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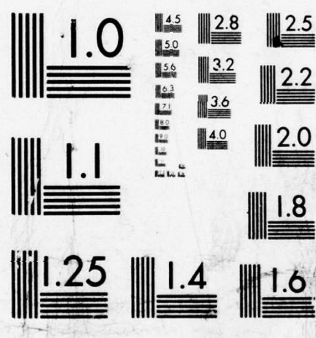

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TECHNICAL REPORT ARPAD-TR-77004

SIMULATION STUDY OF X-RAY SYSTEM FOR THE 105MM HE PROJECTILE M1 MELT-POUR FACILITY AT LONE STAR ARMY AMMUNITION PLANT

EDWARD E. LONIEWSKI

NOVEMBER 1977

U.S. ARMY ARRADCOM
US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
PRODUCT ASSURANCE DIRECTORATE
DOVER, NEW JERSEY

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This report presents the results of a digital computer simulation study of the X-ray system characteristics for the new automated 105 MM HE Projectile Melt-Pour Facility at Lone Star Army Ammunition Plant. The study was performed to provide a comprehensive analysis of the X-ray inspection system and to determine if the system can effectively meet the production requirements within the guidelines of equipment capabilities and safety limitations. →(over)

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A wide range of anticipated product defect rates was investigated applying several sampling plans defined in MIL-STD-1235A, dated 28 June 74. The findings of the simulation study were that two X-ray units with associated conveyor systems, interlinked, would be required to meet the production requirements. This finding is based on the conclusion that, regardless of the sampling plan investigated, the X-ray system would be operating at levels that approach 100% inspection during most of the production cycle. Furthermore, given either one or two X-ray systems, having a second hold building had little effect on the output except that, under mobilization production, it could serve as an added buffer area in the event of equipment failure.

TABLE OF CONTENTS

Figures

INTRODUCTION

During the design criteria phase of the Melt-Pour Facility at the Lone Star Army Ammunition Plant's (LSAAP's) Modernization Project 5752626, plans were developed to provide four cobalt-60 X-ray source units. These four units were to provide the capability for 100% X-ray inspection. However, due to the escalating costs of construction, a decision was made to reduce the number of X-ray cells from four to two and to provide a random sampling plan for the inspection operation. The sampling plan proposed was 1 to 10 with AQL = 0.015%. An operational analysis of the cobalt system and the quality assurance requirements for the 105 mm HE projectile M1 conducted by the System Engineer at Picatinny Arsenal indicated that a high restraint to production would result from the design planned for the X-ray facility. As a result, two alternatives were visible: either the quality assurance requirements would have to be backed off or a different X-ray source had to be identified that could process the explosive-loaded projectiles at a faster rate than was possible with cobalt-60. This problem was formally addressed in July 1974 when it was decided that:

1. The quality assurance requirements could not be compromised; therefore, if necessary, 100% inspection would be required.

2. The 4-MeV X-ray source system (Linatron) could be utilized instead of the cobalt-60.

After a thorough evaluation of the cobalt-60 vs 4-MeV Linatron systems, it was decided jointly by the project manager's office, PA, and LSAAP to change the facility design to provide two 4-MeV Linatron units. This change provided the capability for 100% X-ray inspection without degrading the production rate and proved economically comparable to the cost of two cobalt-60 X-ray cells. The question of sampling (1/10) versus screening (100%) had not as yet been resolved and, as a result, it was proposed by the Project Manager for Production Base Modernization (PBM) to provide only one 4-MeV Linatron unit maintaining the random sampling plan. In January 1975, PBM asked Product Assurance Directorate, Picatinny Arsenal, to assist in evaluating the X-ray needs.

A mathematical model and associated computer program were developed. The results of the analysis indicated that two 4-MeV Linatron units would be necessary.

However, because of the preliminary data and results that had been initially published, the task of modeling the X-ray operation in accordance with specific known production design elements was undertaken. The purpose of this work was to provide an in-depth analysis of the X-ray system, to identify causal relationships, and to define operational alternatives to the X-ray system. To accomplish these goals it became necessary to present a detailed description of exactly what was modeled, what assumptions were made, input values used, and rationale for interpreting the conclusions and results.

PROCESS DESCRIPTION

That portion of the M1 projectile loading line evaluated in this simulation is the basic X-ray system, beginning at the melt-pour operation and ending with exit from the X-ray hold building. It considers the effect of the X-ray system performance on such associated operational areas as melt-pour, cooling hold and X-ray hold. Figure 1 shows the facility layout of the area under evaluation and Appendix A presents a detailed system description of those operations.

Briefly, the operation of the line can be described as follows:

1. Melt-pour units in buildings E-120 and E-123 each produce poured shells at a rate of approximately 24 per minute when both units are operational, for a combined total of 48 per minute. If one unit is down, the other is capable of operating somewhat faster than 24 per minute, but the difference is insignificant.

2. Poured shells are transferred, 16 to a pallet, via enclosed, heated conveyor to the cooling buildings, E-129 and E-130. Which of the two buildings is used is determined by traffic flow. A complete cooling cycle is 83 minutes plus travel time into and out of the building.

3. Cooled shells are transferred to the process hold area, shown as buildings E-131 and E-132. One of the original questions was whether both these buildings would be necessary or only one would suffice. At this point, the shells still have the funnels with explosive risers in place.

4. When a determination is made that the next pallet is due for X-ray, it is transferred from the hold building to X-ray via the funnel-pulling operation, buildings E-133 and E-134, where the funnels and explosive risers are automatically removed.

5. All pallets then travel up to the X-ray building, E-128. Figure 2 depicts the general operations within this building. Once a pallet has arrived from earlier stations, a computer randomly selects specific shells to be X-rayed, depending upon the sampling plan being followed and upon whether the system is in sampling or screening mode. These shells are mechanically placed on an X-ray pallet (of four shells), passed before the X-ray machine, and then replaced on the original pallet, which is then transferred out of the building and downstream. A single X-ray system is rated at a maximum speed of approximately nine exposures per minute, or 36 X-rayed shells per minute.

6. Following X-ray, the pallets are transferred to the X-ray hold building, E-168, until the film has been processed and a decision made concerning critical defects (Appendix E). This processing and decision-making takes approximately 15 minutes. If a pallet is defect free, it is passed to the facing and thread cleaning operations and is of no further interest in this study. If a pallet contains a defect, a change is made in line operation to screening mode (or screening is extended) and the I (inspection)-number is reset. The affected pallet and as many of those that follow it as are necessary to clear the I-number on the computer are re-routed back to X-ray for 100% inspection (of those shells not already X-rayed).

The overriding influence on the output of the line is the speed of the material handling equipment. The entire line is geared to the nominal rate of 48 parts per minute at which the melt-pour units operate. This is the speed required to produce 1,000,000 shells per month, based upon 21 days of three shifts of 8 hours per day, 5 days per week (3/8/5) of 480 minutes per shift at 70% efficiency. Except for fluctuations at the melt-pour units which permit speeds of about 52 per minute under certain circumstances, the line cannot operate faster than 48 parts per minute. This fact has profound effect upon output in those conditions where a "catch-up" capability would be desirable; specifically, following restoration to service of a downed X-ray system.

MODEL DESCRIPTION

Appendix B contains a detailed list of the assumptions and parameters used in this study and Appendix D presents the actual computer program used.

For the purposes for which this study was made, two generalizations were made to the system described in the previous section:

1. Since the outputs from the melt-pour units are essentially merged on their way to the cooling buildings, and since no details were to be modeled in the cool buildings, they were combined into one cooling area with double the capacity of a single building.

2. Since it was decided that the funnel-pulling operation would be essentially perfect and that no specific information was sought from this operation, it was left out of the final model.

Furthermore, the operation of all conveyors was disregarded. The mechanism of the conveyor system was considered perfect. By considering material to be in transit throughout the line at the start of each period of simulation and by running the simulation continuously on a 3/8/5 basis, no loss of information occurs by ignoring the conveyors. Any gaps in material caused by the failure of a particular machine will flow along the conveyor and reach each succeeding machine in turn.

Since it was not decided whether or not there would already be material located on the conveyors, and since it does indeed take a measurable length of time for the first shell produced by the melt-pour to reach the X-ray building, the simulations here can and should be envisioned as beginning at that point in the 3/8/5 cycle when the first pallet has reached the Linatron. Again, such a generalization does not alter the results since following final shutdown of the melt-pour units at the end of the run the remainder of the line can be made to continue to operate until all conveyors are empty and all material is processed. While this is undoubtedly what will actually be done on the line, there is no way of telling how long such a clearing operation will take. Therefore, the computer program merely terminates at the end of the run and reports how many shells are still located at each major station on the line.

Figure 3 is a flow diagram of the operations included in this model and their relationship to each other.

In detail, the model functions in the following manner:

1. At the beginning of each run the user specifies all of the functioning parameters:

a. Number of Linatrons in the system (one or two).

b. Number of cooling hold buildings in the system (one or two).

c. Capacity of buildings C, D, and F.

d. Melt-Pour Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), and Parts-per-Minute rate.

e. Linatron MTBF, MTTR and Parts-per-Minute rate.

f. Nominal Critical Defect Rate.

i. Length of a Shift (in minutes).

j. Length of Simulation (in minutes).

2. The user also specifies the contents of buildings C, D, and F to simulate various configurations of the line. The normal practice is to load the cool buildings (C) almost to capacity and to leave the hold buildings (D and F) empty, as at the beginning of the X-ray operation on a typical shift. (Note that even when the situation being simulated is that of two hold buildings, the program only keeps track of one, with double the capacity of a single building.)

3. Simulated processing then begins sequentially, minute by minute, with the melt-pours. Each melt-pour is looked at separately and a probability of failure is sampled from the MTBF distribution. If the melt-pour does not fail, or if it comes back on line that minute, the specified number of shells are poured and transferred to the cool building. If at the beginning of a minute the contents of the cool building are such that no more shells can be loaded, the melt-pour is stopped for that minute and that fact is kept track of.

4. The cooling building is checked next. If there is room in the hold building, and if there are sufficient shells in the cool building, 48 shells are transferred from the cool building to the hold building. Should the hold building already be full, no shells are transferred. If less than 48 shells are available, the entire contents are transferred.

5. The X-ray system is operated next. A determination similar to that for the melt-pour is made as to whether the Linatrons to be used that minute have failed and, if so, appropriate action is taken. Assuming the X-ray system is up and depending upon which mode (sampling or screening) is in effect and how many shells are available from the hold building, the proper number of shells to be inspected are flagged. No determination is made yet as to critical defects since that requires a 15-minute delay. The number of shells processed by the X-ray system are transferred to the X-ray hold building and an equal quantity is simultaneously removed from the hold building. The only time this procedure is not followed is when a certain number of shells must be inspected 100% from among those already cycled through the X-ray building earlier in sampling mode. These shells have priority over those in the hold building and are processed first.

6. After the film processing delay, the X-ray films taken 15 minutes earlier are inspected. For each shell, a determination is made by sampling from the critical defect distribution as to whether that shell is defective. If all shells X-rayed that minute pass inspection, the number of processed shells represented by the sample of films is released to output and the appropriate counters are incremented (i.e., the number of X-rays taken, the number of shells X-rayed in a particular mode, the number of good shells passed to output). If one or more defects are detected in that group of films, several things happen: the line operation is changed to the screening mode (if the system were in sampling), the I-number is reset, the counter of defects is incremented, the number of non-defective X-rayed shells is passed to output, and all un-X-rayed shells are flagged for 100% inspection. In either event, if the system is in the screening mode at the time a batch of films is inspected (regardless of the mode when that batch was X-rayed) and no defects are found, that number of non-defective X-rayed shells is used to decrease the I-number. Whenever the I-number has successfully been cleared, the system is restored to the sampling mode.

7. The program returns to Step 1 and repeats the entire process until the desired number of minutes of simulated operation has passed.

All told, the program maintains the following counts:

- number of X-rays taken (regardless of mode)
- number of shells actually X-rayed in each mode

- number of defects found
- number of minutes of operation in each mode
- number of minutes melt-pour stopped because of full cooling buildings
- number of minutes Linatron stopped because of empty hold buildings
- number of minutes melt-pour downtime (due to failure)
- number of minutes Linatron downtime (due to failure)
- number of minutes each Linatron is used for inspection (the second Linatron is basically a back-up unit and is only used in screening mode or if the first machine is down)
- number of minutes hold building capacity exceeded
- number of shells passed to output
- number of shells in each building at any instant in time
- number of shells recalled from X-ray hold for 100% inspection and, of that number, how many remain to be inspected at any instant in time.

On the basis of these counts, the number of shells with which the line was initially seeded and the length of a shift, the following statistics are gathered at the end of a run:

- number of shells poured but not yet X-rayed
- number of shells X-rayed but not yet inspected
- number of shells still in the cooling building
- average shells cleared per shift (i.e., poured and X-rayed, but not necessarily inspected, since the inspection can be done after shutdown of the line.)
- percentage of processed shells actually X-rayed
- percentage of time the system was in screening mode
- percentage of time melt-pour and Linatron stopped due to non-failure related problems
- melt-pour and Linatron availability date
- percentage of time hold building capacity exceeded

SIMULATION RESULTS

In order to answer the questions for which this study was made, the following combinations of runs were made:

- three different sampling plans from MIL-STD-1235A: Acceptable Outgoing Quality Level (AOQL) = .018%, .033%, .113%
- all the above at five different sampling frequencies: 1/2, 1/3, 1/4, 1/5, 1/10
- all the above at three different critical defect rates: .001, .002, .003
- all the above at two different options: one Linatron and two hold buildings, vs two Linatrons and one hold building

Thus, there was a total of 90 separate cases to be investigated. Each of these cases was run for three separate periods of 3/8/5 (6300 minutes[1], or 15 shifts each). In other words, 270 runs were made representing 4050 shifts. The results are formally presented in Appendix C (Tables C-1-1 to C-2-3). Because only three runs were actually made at any particular combination of parameters, some of the tables and graphs that follow show apparent inconsistencies in direction. This is a natural consequence of computer simulation with such a small sample size and is not at all disturbing since the results neatly fell into two "ball parks" or output categories which clearly indicated what was going on.

The reason for investigating three different plans from MIL-STD-1235A was to determine the impact of applying the new standard as opposed to retaining MIL-STD-1235. The middle plan (AOQL = 0.033) is the closest plan to the AQL formerly used in 1235. The loosest plan (AOQL = 0.113) is the closest plan to the AOQL formerly used. The tightest plan (AOQL = 0.018) is the current recommendation for inspection where critical defects are involved.

Varying the sampling frequency (and the associated I-number) was studied to see if there would be any effect on output or efficiency.

The three defect rates chosen bracket what is thought to be the expected defect rate. If further runs were warranted, this range of rates would have been expanded.

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[1] Based on 420 minutes of available production time.

While there is a great deal of variation among results when viewed individually, variations which will be dealt with shortly, much information can be gained by averaging-over certain variables. These averages are shown in Tables 1 and 2 for the main question involved: one Linatron vs two. There is a considerable difference between the average output per shift of the two options. One Linatron would turn out an average of around 14,500 shells per shift while two Linatrons boost this average to around 18,100. The other major difference is that one system would result in a forced shutdown of the melt-pour units about 31% of the time because of building capacities being exceeded (even with two hold buildings). Such a situation would occur less than 2% of the time with two systems (even though only one hold building was modeled). The two options, however, are similar in that both would require x-raying around 86% of all shells processed (under these sampling plans and defect rates) and both would be involved in clearing I-numbers around 78% of the time.

The percentage of product that actually has to be inspected is a measure of the cost of the inspection plan under consideration in that each X-ray film costs money. The percentage of time spent on screening is also a measure of the inspection cost since it indicates how often a full crew of inspectors would be needed as opposed to a smaller crew for sampling purposes. Since the results seen in this study show no significant difference between the two operations (one vs two X-ray systems) in regard to these two percentages, what these figures are reflecting is actually the cost of the sampling plan itself, not the manner in which the inspection is carried out. As expected, the tighter the AOQL, the higher these two percentages will be. What is not expected, however, is the alarming level that these percentages apparently reach regardless of the number of Linatrons.

Table 3 gives the I-numbers associated with the different sampling plans mentioned here. Table 4 and Figure 4 show the impact of having to go onto screening following the detection of a critical defect (for I-numbers for 1/10). Essentially, for high I-numbers and moderate defect rates, it's almost impossible to get off screening without finding another defect and having to start all over again.

CONCLUSIONS AND RECOMMENDATIONS

Sufficient data is available now to determine which of the two options should be followed. Although under certain conditions one Linatron processed as many as 16,000 shells per shift, the average of 14,500 projects out to only about 917,000 shells per month (based on 63 shifts). This value

Table 1

Summary for one Linatron - two holds
(averaged over all frequencies)

Target AOQL	Defect rate	Output	Time melt-pour stop (%)	Time Linatron stop (%)	Shell X-rayed (%)	Time Screening (%)
	.0010	14510	33.95	0.00	92.62	88.32
.018	.0020	14500	35.18	0.00	98.20	97.72
	.0030	14340	34.68	0.00	97.94	98.18
	Avg	14450	34.60	0.00	96.25	94.74
	.0010	15117	25.38	0.00	77.55	68.32
.033	.0020	14421	34.78	0.00	94.69	90.91
	.0030	14188	35.88	0.00	98.57	97.50
	Avg	14575	32.01	0.00	90.27	85.58
	.0010	16073	13.82	0.00	50.02	29.19
.113	.0020	14208	29.60	0.00	74.49	56.11
	.0030	13705	35.11	0.00	88.96	74.29
	Avg	14662	26.18	0.00	71.16	53.19
Over all AOQL's	Avg	14562	30.93	0.00	85.89	77.84

Table 2

Summary for two Linatrons - one hold
(averaged over all frequencies)

Target AOQL	Defect rate	Output	Time melt-pour stop (%)	Time Linatron stop (%)	Shell X-rayed (%)	Time screening (%)
	0.0010	18337	0.40	0.60	94.86	90.60
0.018	0.0020	18442	0.02	0.73	97.72	97.67
	0.0030	18376	0.01	0.80	98.02	98.92
	Avg	18385	0.14	0.71	96.87	95.73
	0.0010	18233	0.29	0.30	81.90	68.84
0.033	0.0020	18464	0.42	0.50	95.88	91.73
	0.0030	18633	0.17	0.57	97.78	96.59
	Avg	18443	0.29	0.46	91.85	85.72
	0.0010	17907	3.17	0.05	52.41	23.64
0.113	0.0020	17462	6.91	0.03	79.10	57.74
	0.0030	17611	4.34	0.13	91.17	74.57
	Avg	17660	4.81	0.07	74.23	51.98
Over all AOQL's	Avg	18163	1.75	0.41	87.65	77.81

does not meet the goal of 1,000,000. On the other hand, two Linatrons project out to over 1,100,000 per month. These averages were obtained by assuming that funnel-pulling operations and transfer systems were perfect, that one Linatron results in a significantly inefficient use of the melt-pour units, and that there is nothing in favor of the single system as far as percentage of shells inspected or percentage of time on screening is concerned. Consequently, the decision is clear cut: two Linatron systems are needed to accomplish the mission.

Figures 5 through 11 compare the performances of the two options under the sampling plans considered.

Only if one were willing to make certain additional, drastic assumptions employing a single Linatron could be justified. These assumptions would have to be:

1. The availability of the melt-pour and the Linatron are better than assumed here.

2. The funnel-pulling operation and transfer systems are indeed perfect or else will not degrade production.

3. The actual critical defect rate will be better than the rate used here.

Even though we are dealing with averages over the long run and though it might still be possible to meet the required production rate while sustaining a prolonged breakdown of the single Linatron system, the risks of trying to accomplish the mission with just one system are not warranted, especially in view of questions already being raised about other portions of the line.

In all fairness, the Linatron machine itself is not the culprit in these gloomy forecasts. Industry experience indicates that the actual machine has a failure probability several orders-of-magnitude better than modeled in this study. However, the machine is attended by a host of complex and relatively unreliable mechanical devices for film handling, loading, and processing. It is this array of peripheral equipment that degrades the Linatron's performance to the "black box" figure used here.

Furthermore, and this is a big limitation, the X-ray operation, no matter how many machines there are, is forced by the material handling

Table 3

I-numbers for investigated sampling plans (MIL-STD-1235A)

Sampling frequency	AQL = 0.010% AOQL = 0.018%	AQL = 0.015% AOQL = 0.033%	AQL = 0.065% AOQL = 0.113%
1/2	1540	840	245
1/3	2590	1390	405
1/4	3340	1820	530
1/5	3960	2160	630
1/10	6050	3300	965

Table 4

Probability of clearing I-number on first attempt
(Based on I-numbers for 1-of-10)

Defect rate	I = 920	I = 3300	I = 6050	Expected shells to next defect
.005%	.95504	.84789	.73896	20000.
.010%	.91210	.71891	.54606	10000.
.011%	.89996	.68518	.50000	8729.
.020%	.83192	.51682	.29816	5000.
.021%	.82428	.50000	.28062	4761.
.030%	.75878	.37152	.16279	3333.
.050%	.63121	.19197	.04852	2000.
.075%	.50000	.08322	.00235	1000.
.100%	.39834	.03682	.00235	1000.
.150%	.25132	.00706	.00011	667.
.200%	.15853	.00135	.00001	500.
.250%	.09997	.00026	.00000	400.
.300%	.06303	.00005	.00000	333.
.500%	.00994	.00000	.00000	200.

equipment to process a maximum of 48 shells per minute. No capability for catch-up exists, even with two machines. If there is a breakdown in X-ray, a permanent back-log is created which cannot be reduced (unless, of course, the melt-pour fails, which is not much of a consolation). A second disconcerting fact of this material handling limitation is that a second Linatron cannot be used to its maximum capability. Each machine is rated at 36 X-rayed shells per minute, for a potential of 72 per minute out of two machines. However, since there are only 48 shells available in any one minute, the second machine only gets to look at 12. (Actually, the work would probably be distributed as 24 to each machine.) In any event, this waste of much of the second machine's value (except as a back-up in case of failure of the first machine) gives rise to the often heard comment that "We don't need two Linatrons, just one and a third."

Regarding the choice of one vs two hold buildings, the results of this study indicate that the second building is not required. According to the engineers involved, aside from providing additional process-hold capability, a second hold building would be valuable as a potential third cooling building in the event that problems arise in that operation. The validity of this statement cannot be determined without a study of the likelihood of such a situation's occurring. There seem to be problems with the cooling system, but their impact has not yet been assessed. As far as this study is concerned, the findings indicate the following: without interjecting problems from the cooling system, if two Linatrons are used, the second hold building is not required; while if only one Linatron is used, the second hold building will not help.

The final problem is that of varying the sample plan. Of the three plans evaluated, the loosest (AOQL = 0.113%) still required on the average that no less than 50% of all the shells processed be X-rayed. The other tighter plans require a much higher percentage, with the plan being proposed for critical defects (AOQL = 0.018%) reaching approximately 96%. But the fact remains that such percentages are quite likely. The higher I-numbers of MIL-STD-1235A (Table 3), the reclassification of majors as criticals, the sort of critical defects currently floating around, and the potential imposition of the tightest inspection plan all contribute to this prospect. While one can argue against 100% inspection on the grounds of cost, one can agree with equal merit for complete inspection on the grounds of the consequences of allowing any critical defects to get into the field. Even though no inspection procedure is perfect (even 100% inspection would probably leak some criticals in the field), current trends in liability prosecution indicate that the Government and the contractor (in this case,

Day and Zimmerman) would be hard pressed to justify why 100% inspection were not used. If the choice were between 100% and 10%, cost might be argued successfully, but when the choice is between 100% and anything from 50% to 96% as indicated here, that argument is much less convincing. In view of these results, it is recommended that 100% inspection be given serious consideration.

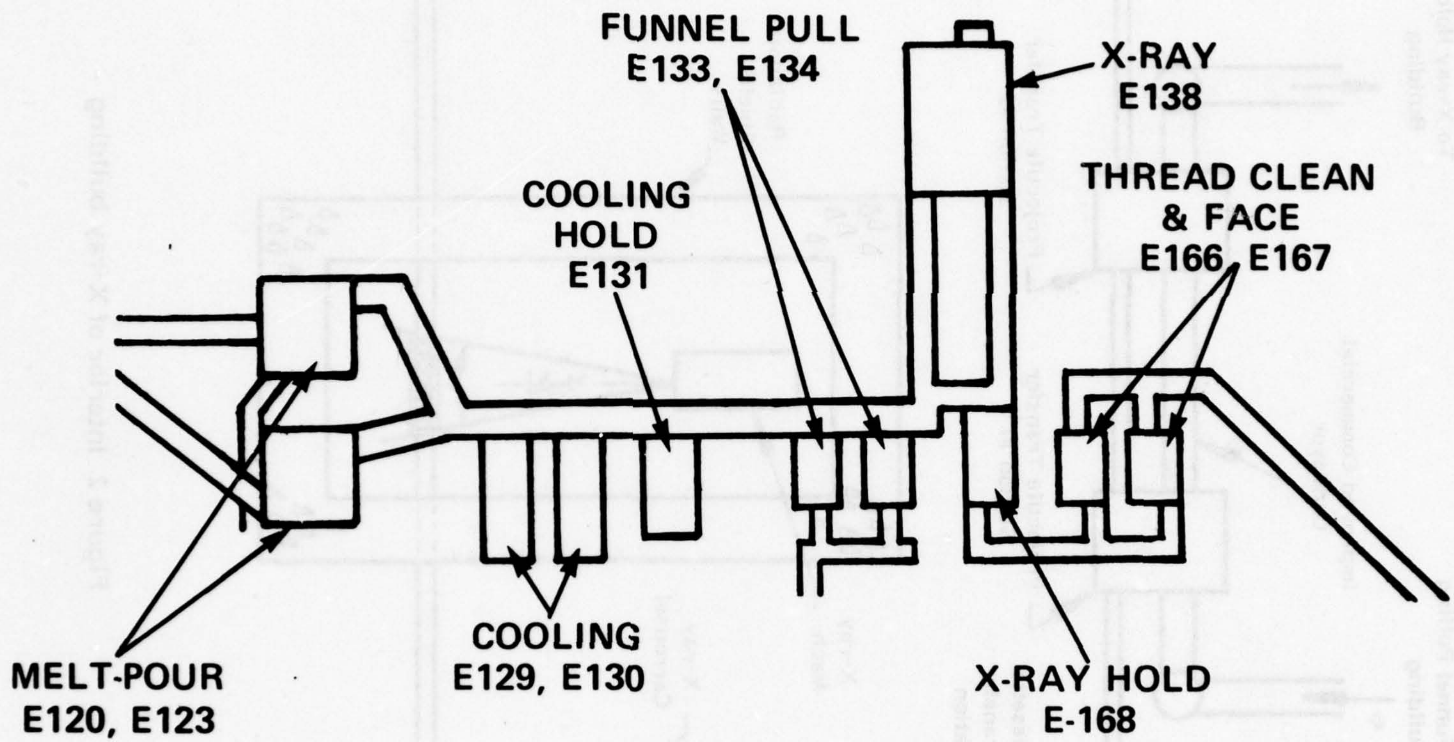


Figure 1 Facility layout

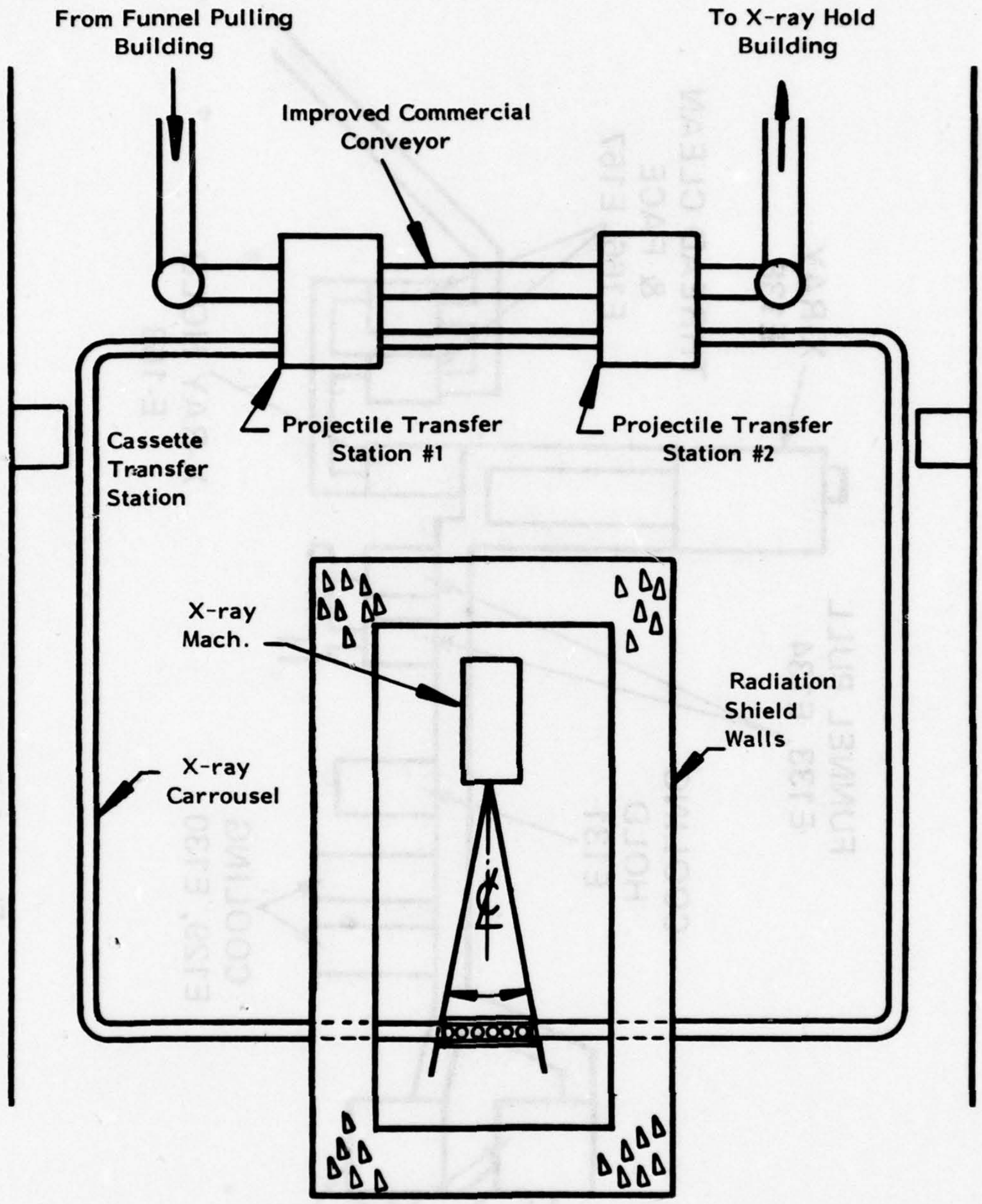
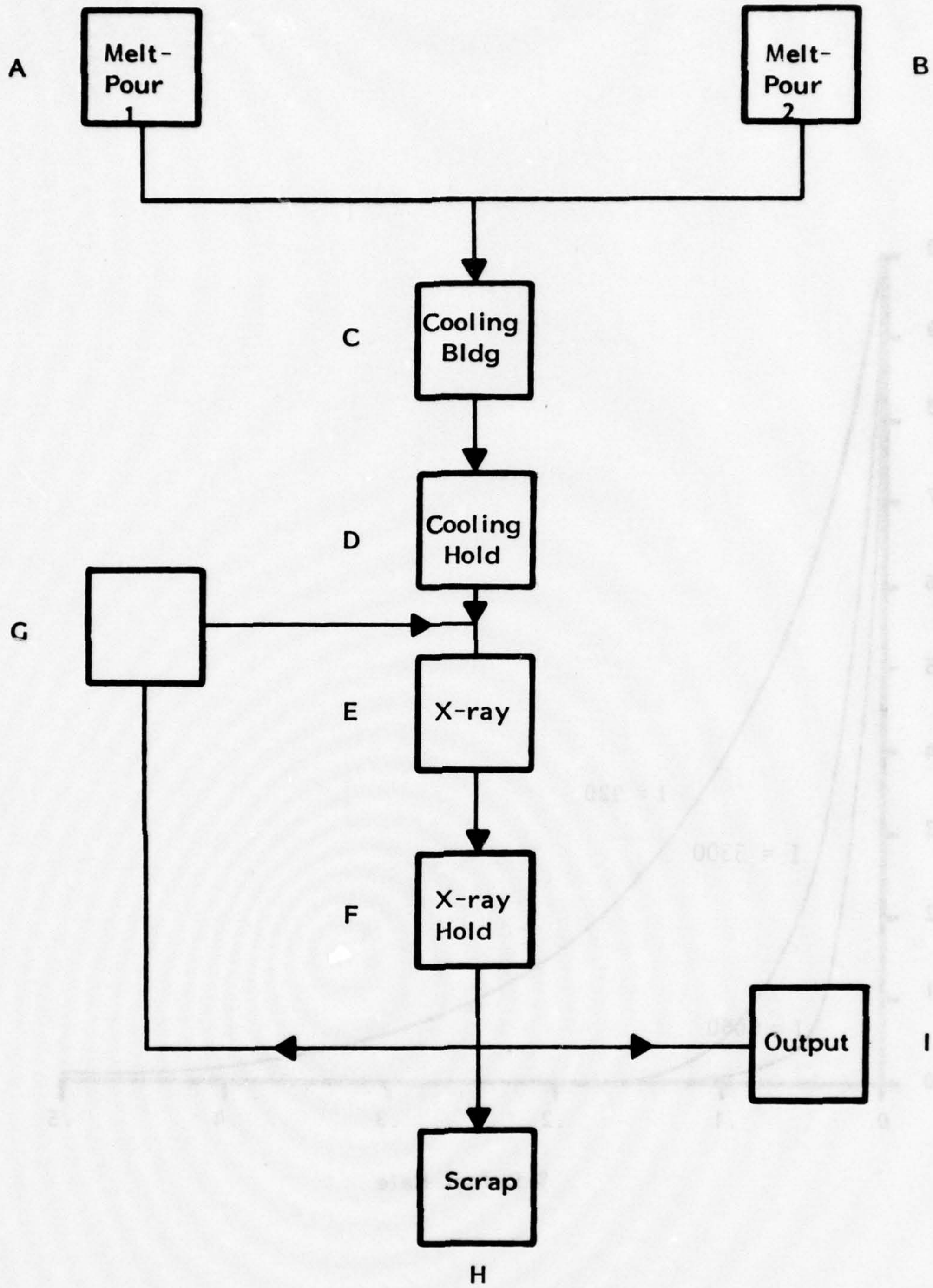


Figure 2 Interior of X-ray building



Note: Following X-Ray Hold, good shells are passed to Output, bad shells to Scrap and, if screening, un-X-rayed shells to Re-Inspection.

Figure 3 Melt-pour system - as modeled

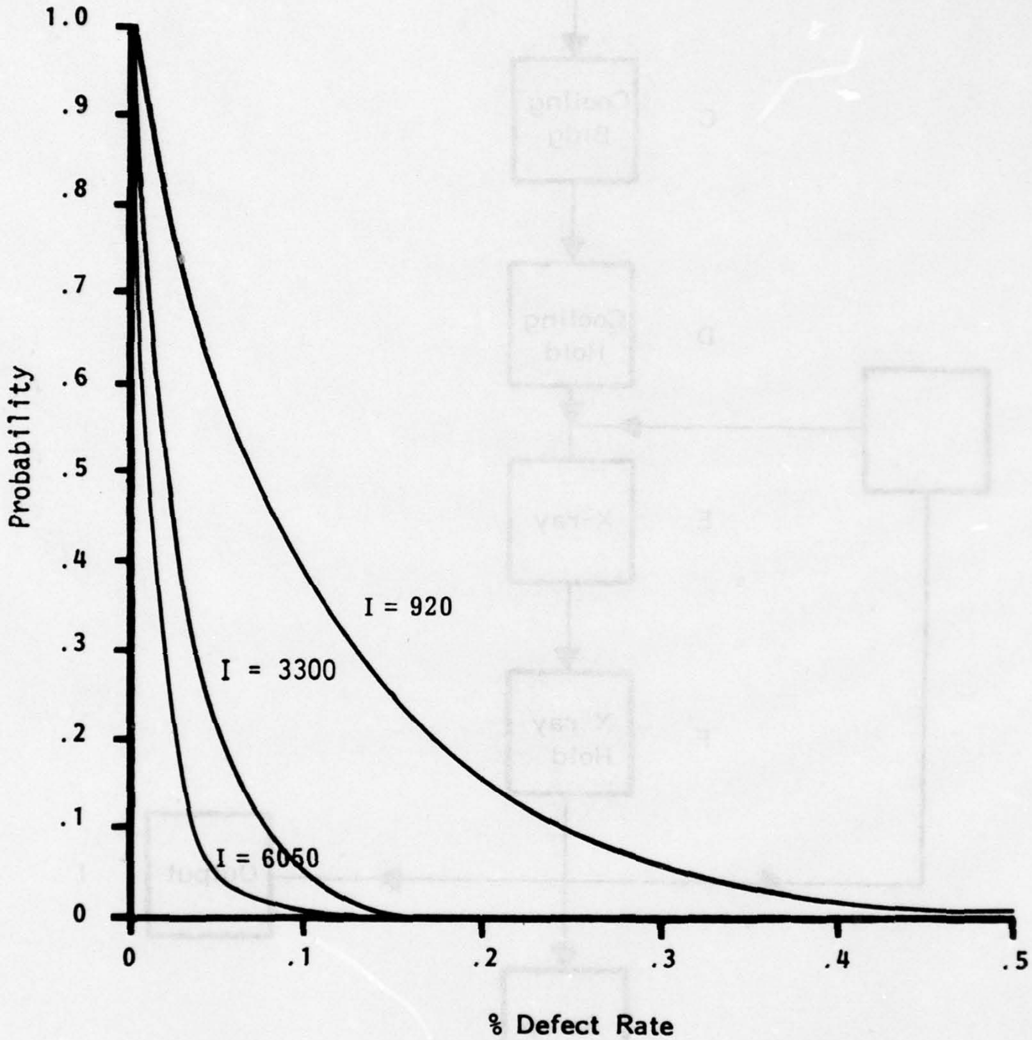


Figure 4 Probability of clearing I-numbers on first attempt

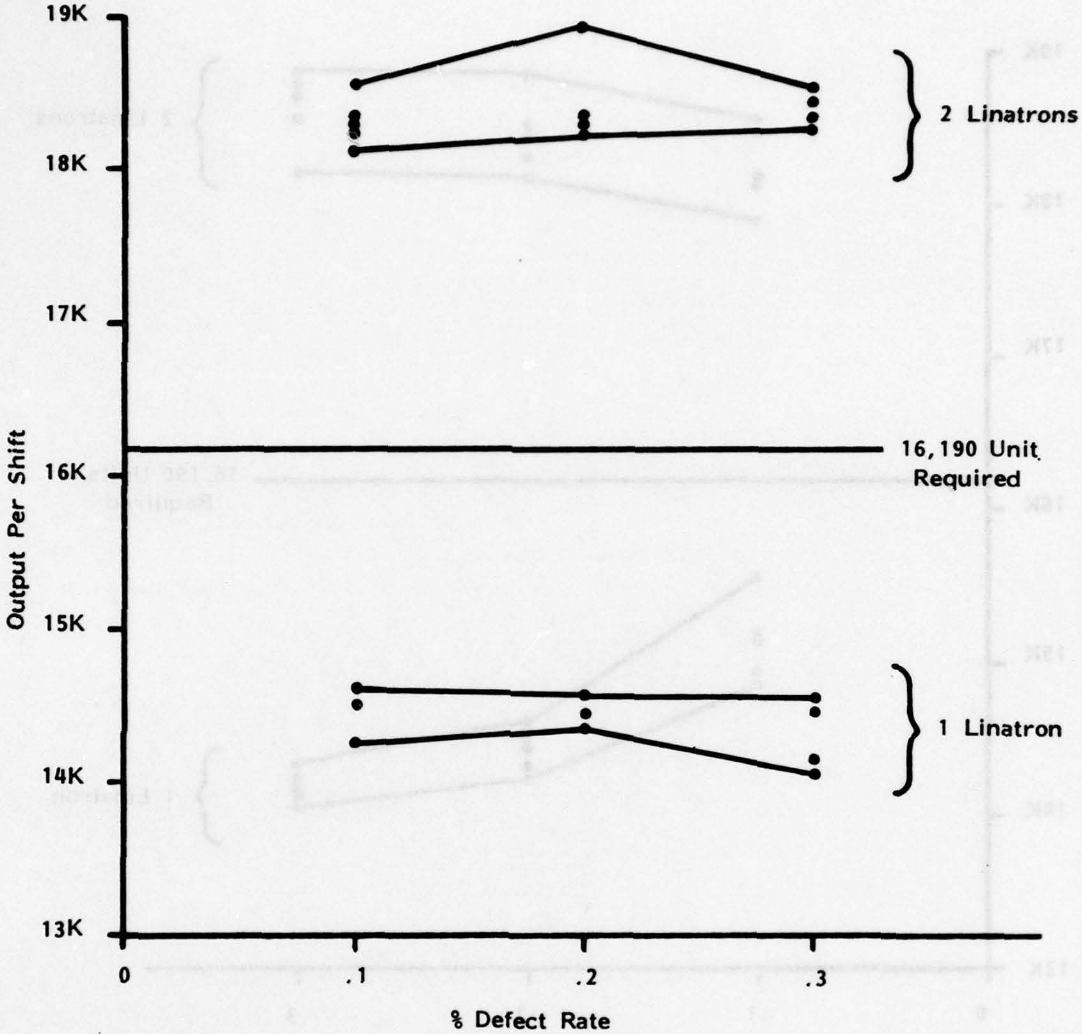


Figure 5 Range of output vs defect rate (AOQL = .018)

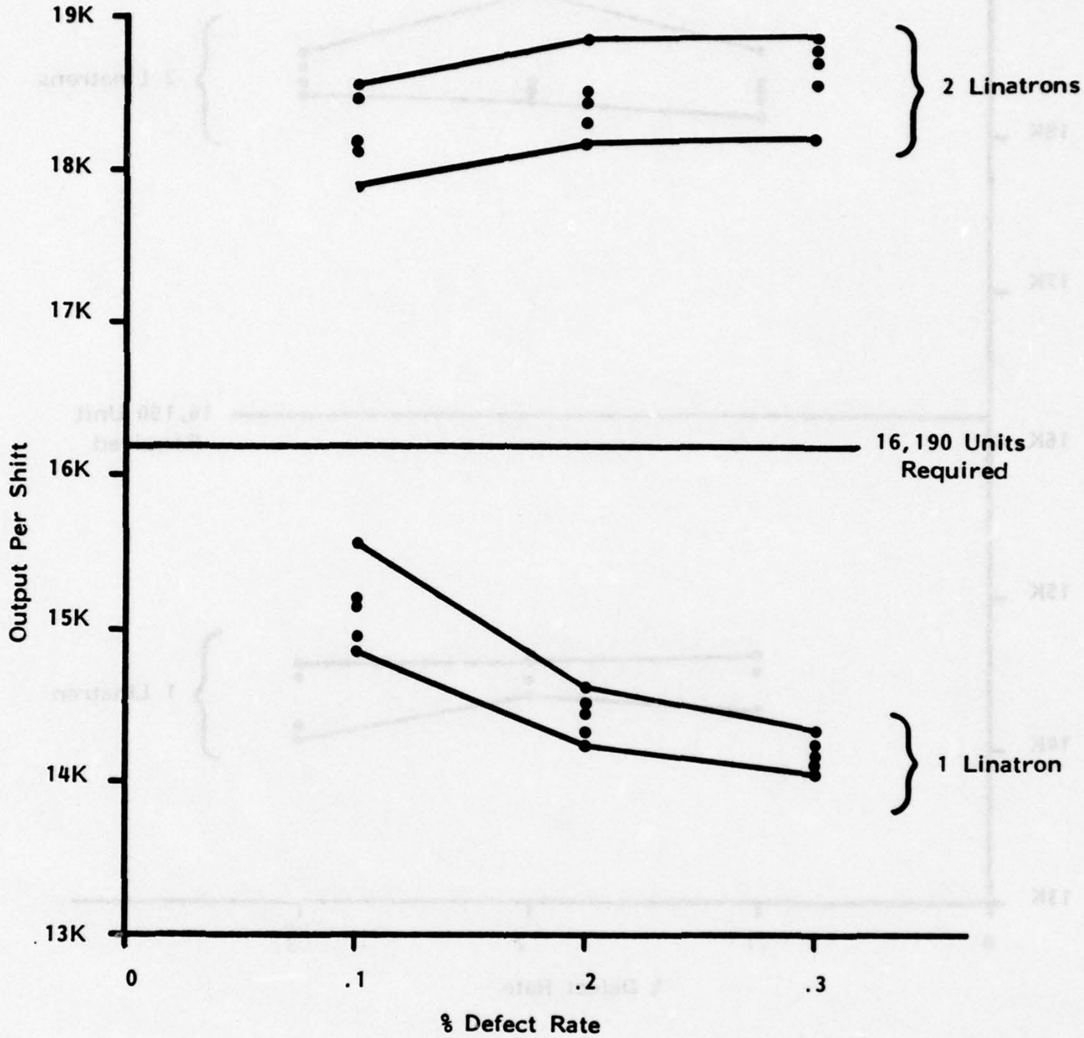


Figure 6 Range of output vs defect rate (AOQL = .033)

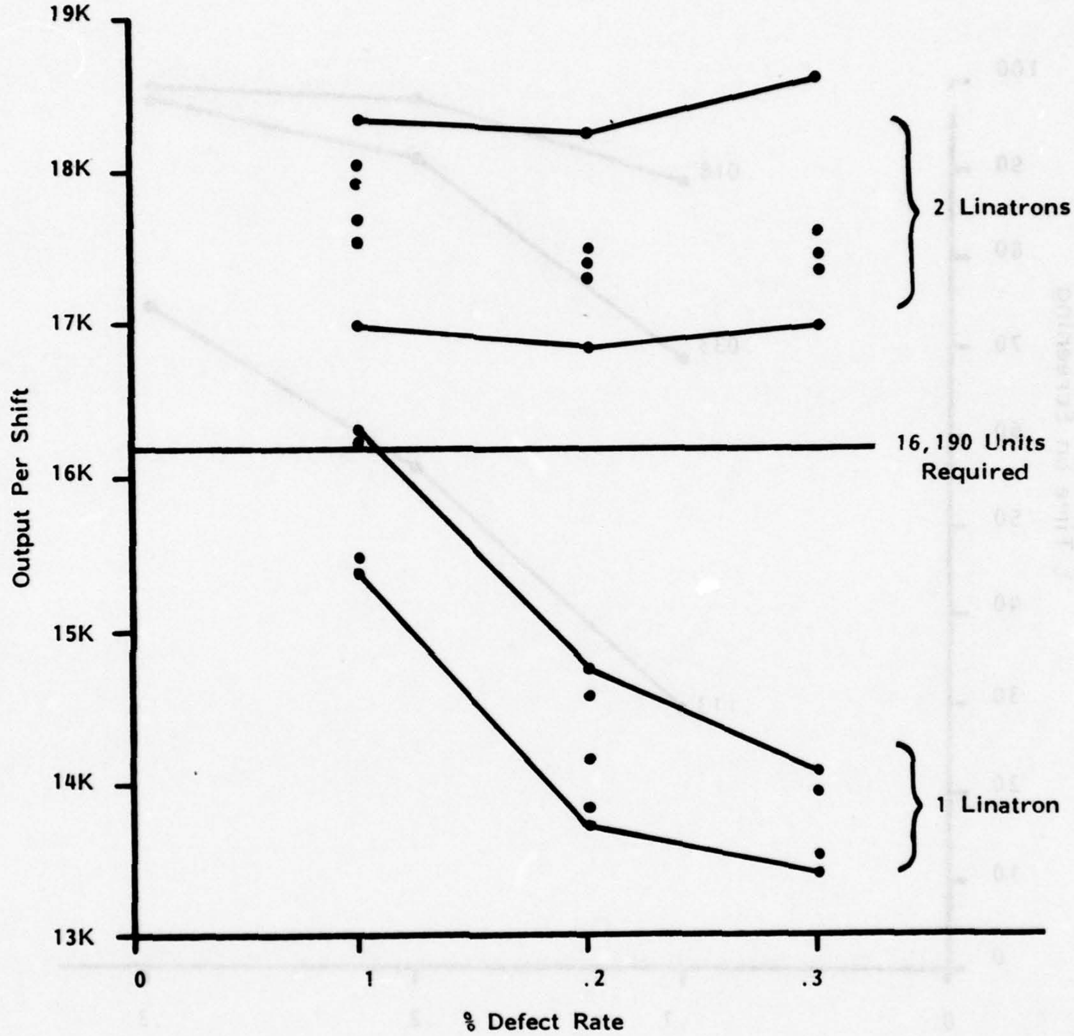


Figure 7 Range of output vs defect rate (AOQL = .113)

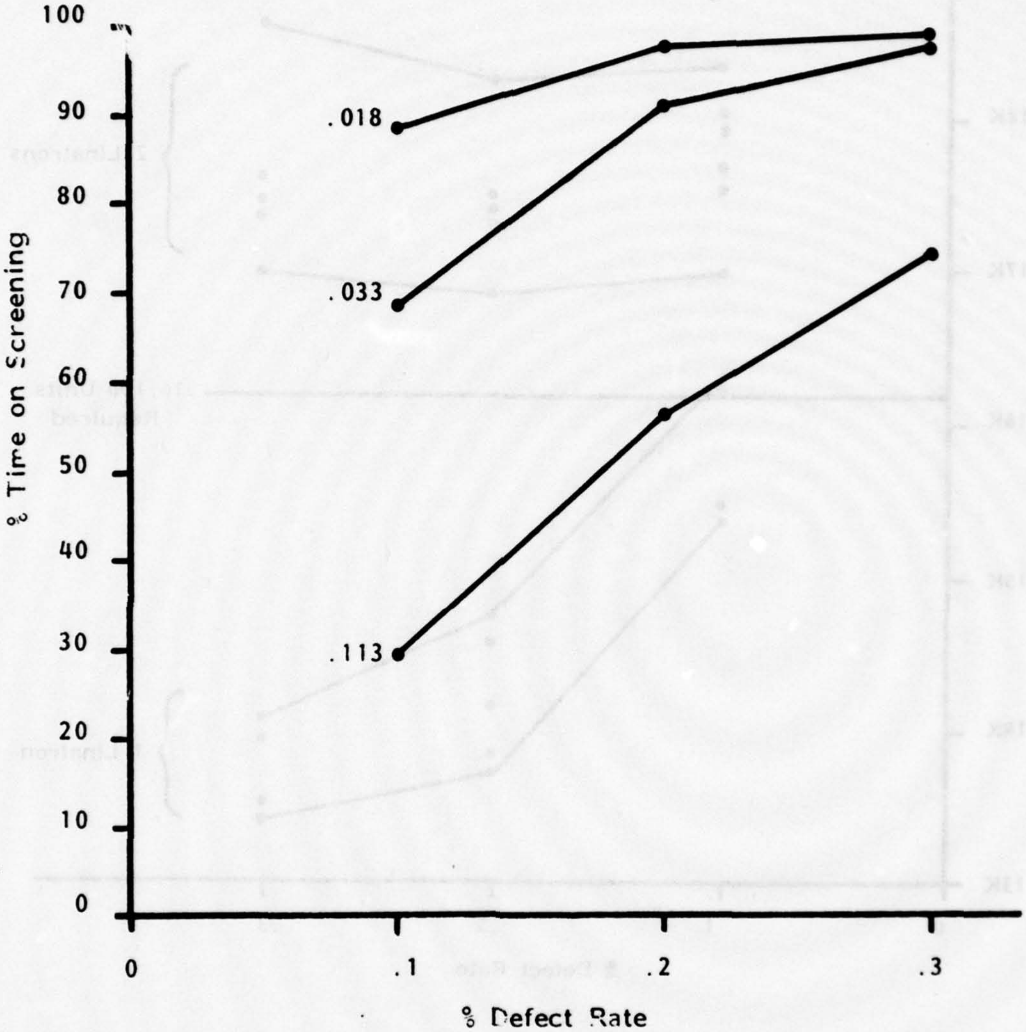


Figure 8 Screening time vs defect rate (By AOQL) (1 Linatron)

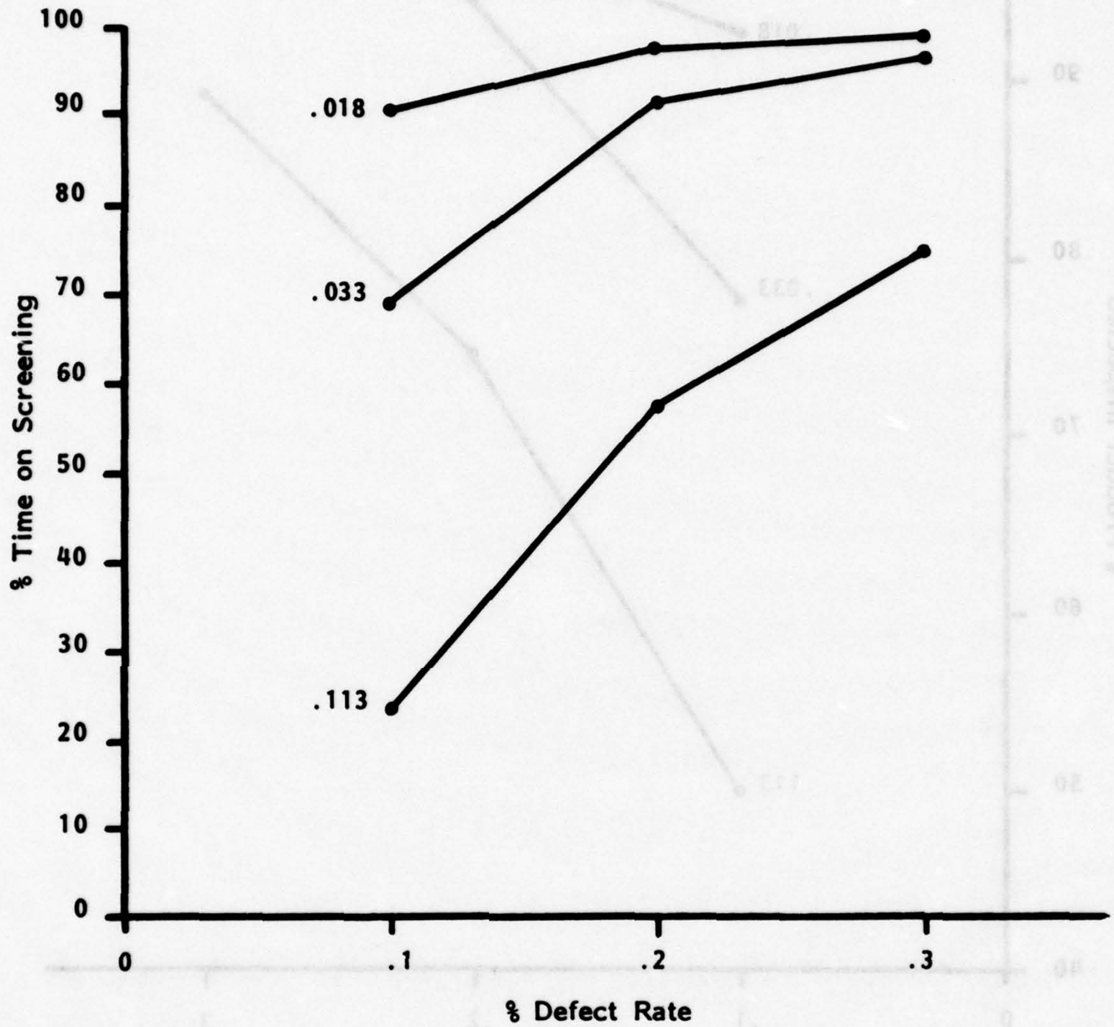


Figure 9 Screening time vs defect rate (By AOQL) (2 Linatrons)

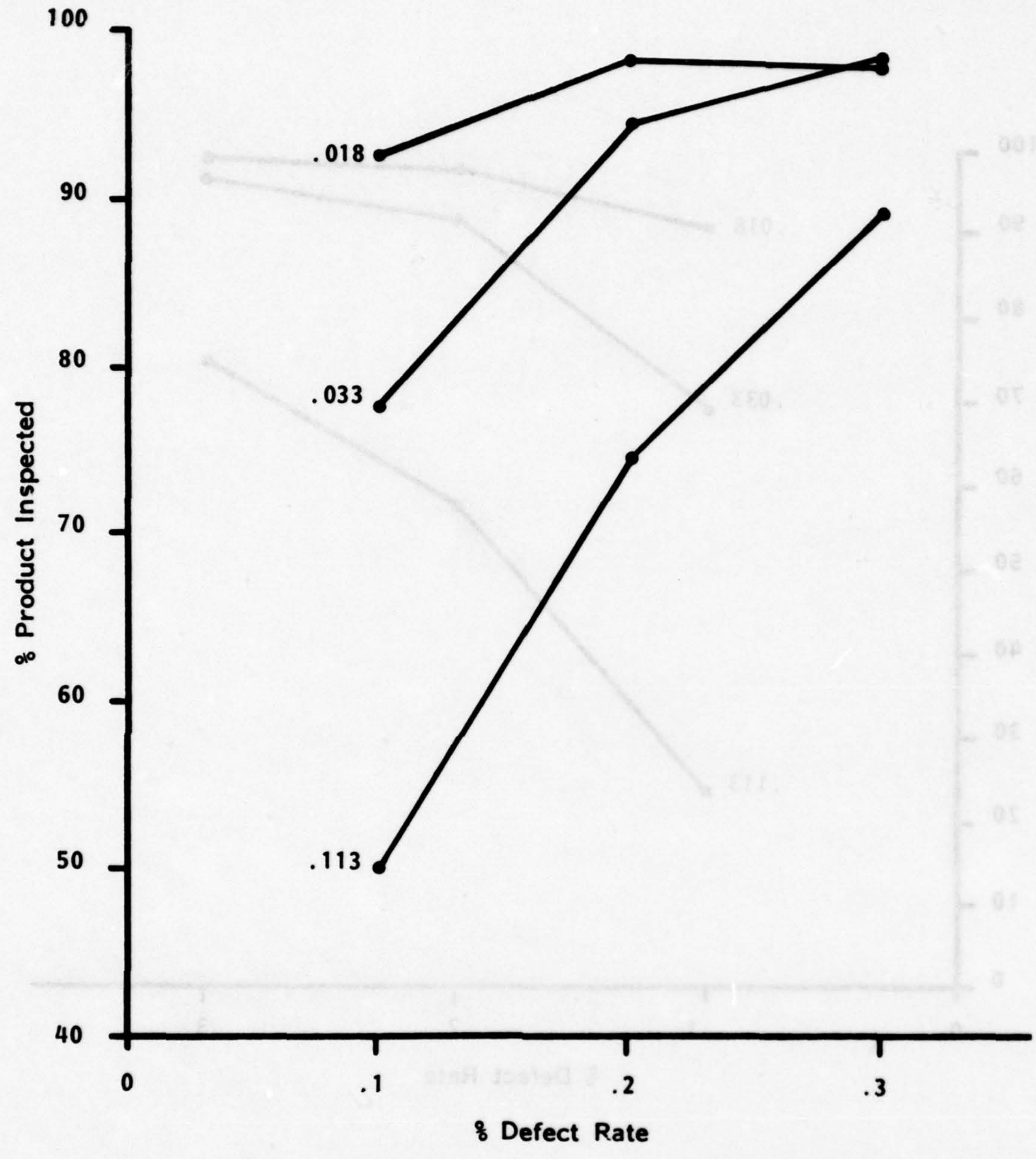


Figure 10 Product inspected vs defect rate (By AOQL) (1 Linatron)

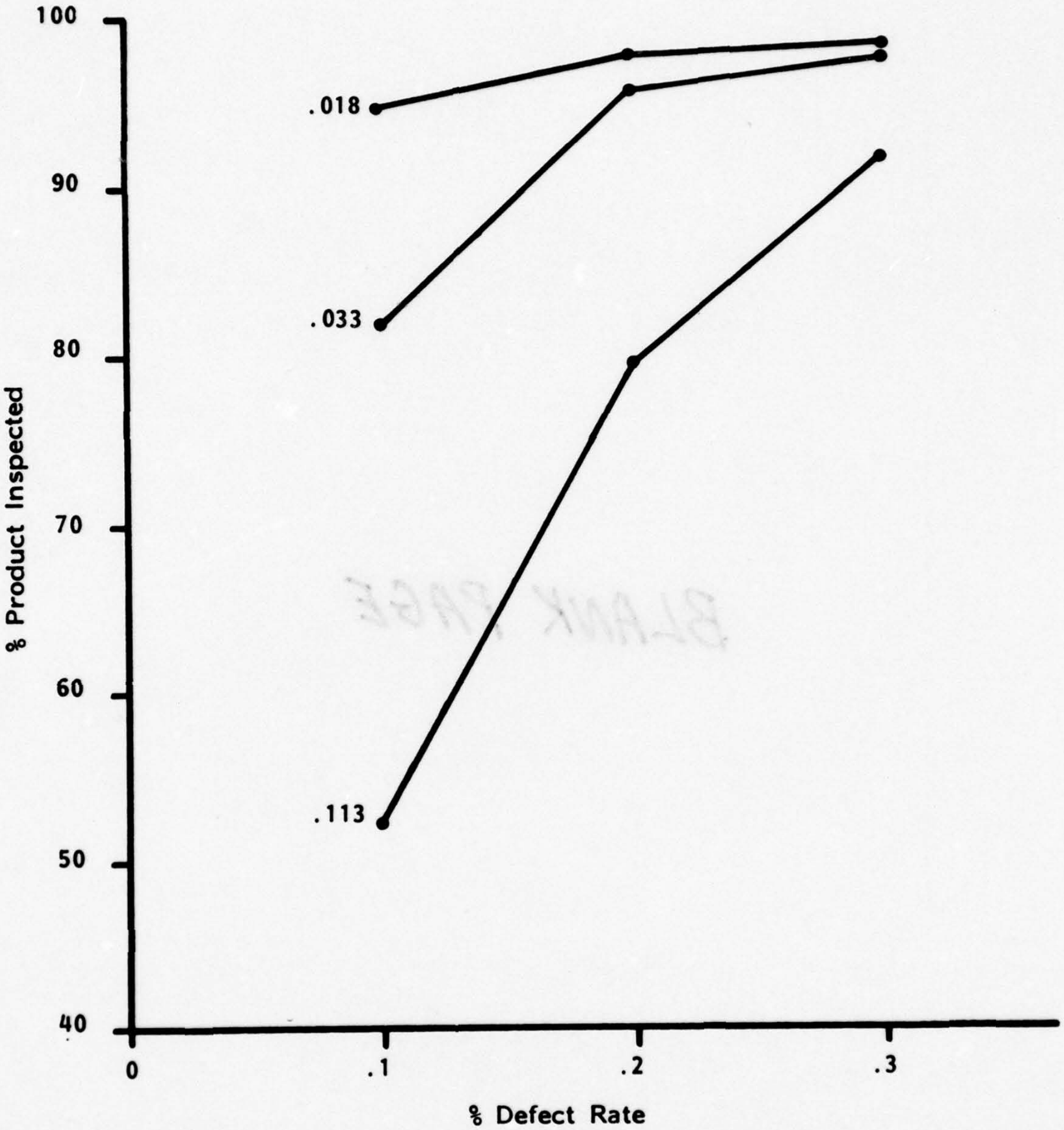


Figure 11   Product inspected vs defect rate (By AOQL) (2 Linatrons)

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APPENDIX A

System Description
Modernization of the Melt-Pour Facilities
for 105 MM Projectile

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SYSTEM DESCRIPTION

The following information presents a detailed account of the operations taking place in the various buildings involved in this study, beginning with melt-pour and ending at x-ray hold.

Melt-Pour Buildings 120 and 123

These buildings receive separated amounts of explosive from Building 125 on belt conveyors. There is one conveyor supplying each building. Each conveyor can supply enough explosive for 28 projectiles a minute. The availability of each conveyor is 99%. The maximum explosive limit of each building is 2500 pounts (1130 kg). The two melt pour buildings are in parallel. Each building consists of one melt unit, two explosive pumps with related process piping, and two pour units. The explosive is automatically transferred into the melt units. Each melt unit can supply enough explosive for 26 projectiles a minute. The availability of each melt unit is 98%.

The molten explosive is transferred through process piping by means of a diaphragm-type explosive pump. Each pump with piping is capable of transferring enough explosive for 32 projectiles/minute and simultaneously recycling through the melt unit any explosive above the amount required by the pour units. The two pumps are in parallel; one is held as a back-up. The availability of each pump with piping is 95%.

The two pour units are in parallel and each unit can supply enough explosive for 14 projectiles a minute. The availability of each pour unit is 98%. Projectiles are supplied to each pour unit by conveyor.

If a failure occurs in a melt-pour building, maintenance may not be performed while any explosive equipment is operating in that building. Permanent personnel will not be stationed in these buildings. Maintenance response time is 2.56 minutes by truck from Building 2.

Cooling Igloos, Building 129 and 130

The cooling igloos receive explosive-filled projectiles from the melt-pour buildings by means of the conveyor, at 16 projectiles per carrier. The two cooling igloos are in parallel, and the conveyor will supply one igloo at a time.

Each cooling igloo consists of eight controlled cooling units in parallel. Each cooling unit can hold 320 projectiles; but, due to the maximum explosive limit of 15,000 pounds (6800 kg) per igloo, only 2112 projectiles are allowed in each igloo at a time. Once the cooling igloos are loaded to capacity, cooled projectiles will exit the igloos at the same rate that poured projectiles enter them. The availability of each cooling unit is 95%. If a cooling unit becomes inoperative, the projectile will be removed from that unit and maintenance may be performed while the other units are operating. Maintenance response time for Building 129 is 3.1 minutes and for Building 130 is 3.0 minutes. Permanent personnel will not be stationed in these buildings; therefore, maintenance personnel must walk from Building 12 or 138.

Process Hold Building 131

The purpose of the Process Hold Building is to provide buffer storage for the system as needed. During normal production, the projectiles will bypass the process hold building and proceed directly to the funnel-pulling buildings. In the event of a production stoppage, subsequent to the process hold, the projectiles will be held in temporary storage without affecting production operations prior to process hold until the building is loaded to capacity. Due to the building's maximum explosive limit of 10,000 pounds, (4356 kg), the maximum number of projectiles allowed in the building at one time is 1408. The projectiles remain in the carriers on the conveyor while in process hold; therefore, any failure must be attributed to the conveyor. Maintenance response time for this building is 2.01 minutes. Permanent personnel will not be stationed in this building; therefore, maintenance personnel must walk from Building 12 or 138.

Funnel-Pulling Buildings 133 and 134

These buildings receive projectiles from the cooling igloos by means of the conveyor. The two buildings are in parallel and each building contains one station which automatically removes the funnels from the projectiles and places them in carriers on a separate conveyor system for transfer to the Riser Ejector Building. Each station can function at the rate of 48 projectiles per minute. The availability of each station is 95%. Maintenance response time for each builing is 2.0 minutes. Permanent personnel will not be stationed in these buildings. Maintenance personnel must walk from Building 12 or 138. The maximum explosive limit for each building is 500 pounds (227 kg).

X-ray Building 138

This building receives projectiles by conveyor, from funnel-pulling building. The X-ray Building contains the Linatron X-ray unit(s), six film-processing units, one film cassette conveyor, and one carrousel projectile conveyor.

The projectiles are placed on the carrousel conveyor and transferred to the X-ray unit. After exposure the projectiles are replaced on the conveyor and transported to the X-ray Hold Building. The film cassettes are placed on the cassette conveyor and transferred to the film processing units.

During normal production the X-ray system is in a sample mode when a random sample is taken. The system is capable of supporting the 48 projectiles a minute production rate while in the sample mode.

If a reject is discovered, the system goes into the 100% screening mode. Screening is performed on a specific number of projectiles depending upon the sample plan. This usually means that approximately 720 projectiles which have passed the X-ray system must be recycled due to the 15-minute film development period. During 100% screening the X-ray system can operate at 36 projectiles a minute. The availability of the system is 95%.

The building's maximum explosive limit is 2,000 pounds (907 kg). Permanent personnel will be stationed in this building. The maintenance response times are as follows:

X-ray unit	5.0 minutes
Film processing units	0.25 minutes
Cassette conveyor	2.5 minutes
Carrousel conveyor	0.35 minutes

X-ray Hold Building 168

Projectiles enter the building on the conveyor. The projectiles remain in X-ray hold approximately 15 minutes awaiting development of the X-ray film before proceeding to the next operation. The projectiles remain in the carriers on the conveyor while in X-ray hold; therefore, any failure must be attributed to the conveyor.

The building's maximum explosive limit is 5,000 pounds (2268 kg). The maintenance response time for this building is 1.87 minutes. Permanent personnel will not be stationed in this building. Maintenance personnel must walk from Building 12 or 138.

APPENDIX B

Simulation Design Parameters

The following information briefly summarizes the specific quantitative values that were used to perform this study.

1. System Operation

a. Production - 1 million units/month, 500-hour base, 70% JCAP (Joint Conventional Ammunition Production).

b. X-ray capability design effectiveness - 36 parts per minute per X-ray unit.

c. Available production minutes - 420 minutes.

d. Explosive capacity Cooling Hold Building - 1408 projectiles.

e. Explosive capacity X-ray Hold Building - 1072 projectiles.

2. The 105 mm Melt-Pour production line, as currently planned, can be represented by the flow chart on Figure 3.

3. The modification or assumptions used in this study are as follows:

a. There is only one melt-pour system (consisting of two melt units and four pour units).

b. The melt-pour units produce 48 units per minute when both are operational. They will stop if Cooling Building becomes full (approximately 4160 shells).

c. Concentrate on operations E and F (Fig 3) as follows:

1. Vary the number of X-ray systems from 1 to 2, with an availability of 0.95.

2. The X-ray systems handle nine X-rays per minute regardless of mode.

3. The second X-ray system, if present, only operates on a screening mode or if the first system is down.

4. Sample on various frequencies and use associated I-numbers from MIL-STD-1235A.

5. Fifteen minute decision time for X-ray processing.

6. Switchover to screening mode instantaneous.

7. Vary X-ray projectile cast defect rate from 0.1 to 0.3 percent.

8. Vary the number of Cooling Hold Buildings from 1 to 2.

9. Fix the X-ray Hold Building capacity at 1072 projectiles.

10. Stop X-ray system if capacity of X-ray Hold Building is exceeded.

APPENDIX C

Summary Tables and Sample Output

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Contained in this appendix are summary tables showing the averages of the simulation results for the major combinations studied by operation, by AOQL, by defect rate, and by sampling frequency. More detailed tables are available on request. Also shown is a printout from the simulation program. The tables are preceded by some explanatory notes.

In interpreting these tables several things must be kept in mind:

- all runs were made by inputting the following availability data for the major operations:

Operation	MTBF	MTTR	Avail	Prob of failure in a minute
Melt-Pour	540	60	.90	.001851
Linatron	570	30	.95	.001754

- the columns headed "Melt-Pour Avail" and "Linatron Avail" are the calculated values at the end of the simulation. As expected they vary from the input values and are useful in judging why certain other parameters may or may not "make sense".

- while certain values show definite trends (i.e., increasing with increased defect rate or decreasing with tightened AOQL, etc.) other values seem to jump around. Whether these values are indeed random or simply have not yet averaged out can only be determined by making more runs. This is a natural consequence of computer simulation; highly related variables will show up quickly while less strongly related variables require more simulations to distinguish. Since there was enough information available from these runs to make the necessary decisions, it was not felt worthwhile making additional runs just to pin down these few fluctuating values.

- shifts were simulated as being 420 minutes long; while it is true that all the equipment per se could run by itself for 480 minutes, to include the melt-pour which could be manually fed an excess of flake Comp B prior to "breaks", there is no way to make up for the film-readers and other essential personnel. Staggering "breaks" during non-peak periods might lead to better efficiency, but there is no way of knowing if that will be done.

- *The printout is more or less straightforward*; the columns of data relate the status of machines, current contents of buildings, and cumulative totals as of the end of that minute (shown after each of the 15 shifts); for melt-pour and Linatron status, "o" means up and "1" means down; for mode, "1" means sampling and "2" means screening; "DUE" represents how many shells must still be inspected 100% from whatever may have been in X-ray hold when the last defect was found; "KNUM" is what remains of the current I-number still to be cleared; "NDEF" is cumulative defects found.

- two critical defect rates are shown on the printout; the program has the capability of using one distribution while sampling and another while screening; all these runs, however, used equal distributions in both modes.

TABLE C-1-1

1 LINATRON - 2 HOLDS

AOQL= .018%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	14546	29.50	.9145	0.00	.9354	88.34	74.24
	1/ 3	14519	36.27	.9429	0.00	.9500	91.46	87.38
.0010	1/ 4	14604	31.91	.9130	0.00	.9521	92.26	90.84
	1/ 5	14638	33.28	.9197	0.00	.9555	93.29	93.25
	1/10	14245	38.79	.9351	0.00	.9410	97.74	98.45
	1/ 2	14359	36.63	.9301	0.00	.9549	97.80	93.99
	1/ 3	14582	30.51	.9015	0.00	.9659	98.45	98.40
.0020	1/ 4	14479	36.55	.9283	0.00	.9583	98.60	98.97
	1/ 5	14572	38.98	.9448	0.00	.9659	98.74	99.11
	1/10	14508	33.25	.9105	0.00	.9582	97.42	98.14
	1/ 2	14188	37.41	.9271	0.00	.9430	99.28	99.12
	1/ 3	14527	31.33	.9026	0.00	.9643	99.13	99.37
.0030	1/ 4	14272	34.30	.9125	0.00	.9466	98.83	99.18
	1/ 5	14214	36.75	.9261	0.00	.9423	98.73	99.14
	1/10	14497	33.62	.9174	0.00	.9481	93.74	94.95

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TABLE C-1-2

1 LINATRON - 2 HOLDS

AQOL= .033%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	15125	24.18	.9208	0.00	.9492	79.30	52.62
	1/ 3	15113	22.33	.9027	0.00	.9600	77.05	65.79
.0010	1/ 4	14883	27.17	.9171	0.00	.9475	77.36	70.39
	1/ 5	14907	28.60	.9157	0.00	.9606	81.01	77.66
	1/10	15558	24.64	.9199	0.00	.9639	73.03	75.12
	1/ 2	14241	33.75	.9262	0.00	.9459	92.12	77.21
	1/ 3	14298	38.70	.9406	0.00	.9555	97.06	94.30
.0020	1/ 4	14426	34.91	.9281	0.00	.9513	93.60	91.57
	1/ 5	14535	33.34	.9168	0.00	.9590	95.81	95.73
	1/10	14603	33.22	.9150	0.00	.9583	94.88	95.72
	1/ 2	14032	37.88	.9317	0.00	.9442	98.22	92.09
	1/ 3	14316	33.22	.9083	0.00	.9519	98.57	98.13
.0030	1/ 4	14200	36.28	.9216	0.00	.9410	98.56	98.95
	1/ 5	14180	34.55	.9087	0.00	.9415	98.92	99.26
	1/10	14212	37.46	.9280	0.00	.9429	98.57	99.09

TABLE C-1-3

1 LINATRON - 2 HOLDS

AOQL= .113%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	16310	12.67	.9145	0.00	.9526	65.18	23.09
	1/ 3	15341	18.94	.9241	0.00	.9591	59.22	33.37
.0010	1/ 4	15436	19.88	.9391	0.00	.9545	52.26	34.22
	1/ 5	16290	10.35	.9057	0.00	.9577	41.69	27.58
	1/10	16990	7.26	.8995	0.00	.9671	31.74	27.67
	1/ 2	14727	25.75	.9289	0.00	.9511	77.46	39.47
	1/ 3	13721	31.48	.9334	0.00	.9440	76.21	52.53
.0020	1/ 4	14178	28.07	.9273	0.00	.9671	72.44	56.45
	1/ 5	13852	34.58	.9429	0.00	.9500	76.78	64.77
	1/10	14560	28.11	.9150	0.00	.9417	69.58	67.34
	1/ 2	14096	32.58	.9394	0.00	.9592	86.58	55.09
	1/ 3	13460	34.22	.9199	0.00	.9497	88.47	70.01
.0030	1/ 4	13448	35.26	.9240	0.00	.9434	87.95	75.69
	1/ 5	13541	38.02	.9327	0.00	.9454	91.27	82.34
	1/10	13980	35.45	.9225	0.00	.9396	90.51	88.26

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TABLE C-2-1

2 LINATRONS - 1 HOLD

AOQL= .018%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	18585	1.15	.9210	.11	.9510	90.55	73.68
	1/ 3	18394	0.00	.8973	.82	.9592	95.29	91.39
.0010	1/ 4	18122	0.00	.8873	.33	.9521	95.28	93.85
	1/ 5	18313	.36	.8967	.83	.9432	96.16	95.91
	1/10	18271	.48	.8912	.93	.9535	97.02	98.16
	1/ 2	18243	0.00	.8942	.54	.9511	97.20	93.32
	1/ 3	18296	0.00	.8933	.48	.9555	98.11	98.90
.0020	1/ 4	18397	0.00	.8947	1.20	.9631	98.01	98.78
	1/ 5	18329	.10	.8957	.68	.9585	98.24	99.35
	1/10	18945	0.00	.9246	.75	.9480	97.05	98.02
	1/ 2	18447	0.00	.9007	.68	.9621	98.36	98.58
	1/ 3	18288	0.00	.8922	.92	.9513	98.29	99.20
.0030	1/ 4	18288	0.00	.8969	.58	.9551	98.32	99.26
	1/ 5	18343	.02	.8953	.65	.9497	98.24	99.39
	1/10	18516	.02	.9005	1.18	.9450	97.05	98.18

TABLE C-2-2

2 LINATRONS - 1 MOLD

AOCL= .033%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	18125	.29	.8908	.27	.9529	79.83	48.20
	1/ 3	17889	.11	.8772	.04	.9353	78.92	62.96
.0010	1/ 4	18463	.55	.9130	0.00	.9257	80.65	70.99
	1/ 5	18168	.48	.8982	.48	.9359	82.94	76.35
	1/10	18518	0.00	.9018	.70	.9583	87.16	85.72
	1/ 2	18172	1.78	.9019	.55	.9517	93.68	77.78
	1/ 3	18499	0.00	.9049	.54	.9488	95.46	91.00
.0020	1/ 4	18321	.30	.8965	.82	.9629	96.00	94.76
	1/ 5	18475	0.00	.9044	.39	.9438	96.58	96.36
	1/10	18855	0.00	.9229	.20	.9609	97.70	98.75
	1/ 2	18217	.46	.8972	.86	.9457	97.72	90.97
	1/ 3	18561	.12	.9098	.58	.9471	97.63	96.21
.0030	1/ 4	18853	.06	.9192	.65	.9613	98.18	98.96
	1/ 5	18721	.12	.9198	.41	.9406	98.26	98.90
	1/10	18812	.09	.9224	.35	.9554	97.10	97.92

TABLE C-2-3

2 LINATRONS - 1 HOLD

AOQL= .113%

DEFECT RATE	SAMPLING FREQUENCY	OUTPUT	% TIME MELT/POUR STOP	MELT/POUR AVAIL.	% TIME LINATRON STOP	LINATRON AVAIL.	% SHELL X-RAYED	% TIME ON SCREENING
	1/ 2	17936	3.86	.9112	0.00	.9505	67.79	23.67
	1/ 3	17532	5.54	.9107	0.00	.9465	61.39	32.00
.0010	1/ 4	17684	3.38	.8990	.20	.9497	52.49	30.06
	1/ 5	18044	2.75	.9102	.03	.9534	47.37	29.56
	1/10	18340	.30	.8993	.04	.9629	32.99	23.89
	1/ 2	17473	13.39	.9407	0.00	.9592	79.09	40.00
	1/ 3	16840	8.26	.8968	0.00	.9524	83.00	57.13
.0020	1/ 4	17342	7.39	.9211	0.00	.9536	81.61	63.32
	1/ 5	17400	3.09	.8874	.16	.9617	79.67	63.77
	1/10	18257	2.43	.9248	0.00	.9475	72.12	64.46
	1/ 2	17371	10.07	.9167	0.00	.9628	88.24	55.84
	1/ 3	16956	4.41	.8758	.19	.9449	92.04	70.88
.0030	1/ 4	17484	4.20	.9032	.03	.9497	91.64	76.62
	1/ 5	17600	2.53	.8887	.30	.9501	93.19	82.62
	1/10	18642	.40	.9204	.14	.9472	90.74	86.91

105MM LINATRON INSPECTION SIMULATION

NO. OF HOLD BUILDINGS= 1
NO. OF LINATRONS= 2
COOLING BUILDINGS SEEDED WITH 2048.
TOTAL HOLD SEEDED WITH 0.
TOTAL HOLD CAPACITY= 1408.
X-RAY HOLD CAPACITY= 1072.

MELT POUR FAILURE DATA- .001852 60.00 24.00 (NOMINAL AVAIL.= .9000)
LINATRON FAILURE DATA- .001754 30.00 36.00 (NOMINAL AVAIL.= .9500)

CRITICAL DEFECT RATES= .00300 WHILE SAMPLING .00300 WHILE SCREENING

I-NUMBER= 1820 WITH SAMPLING 1 OUT OF 4
LENGTH OF SIMULATION= 6300 MINUTES (15. SHIFTS)

MINUTE	COOL HOLD	MELTPOUR STATUS		HOLD	DUE	LINATRON STATUS		XRAY HOLD	MODE	FINAL OUTPUT	SHELLS SAMPLED	SHELLS SCREENED	KNUM	NDEF
420	1144.	0	0	996.	0.	1	0	648.	2	18472.	696.	16308.	1820	41
840	744.	0	0	1360.	0.	0	0	720.	2	37143.	696.	35040.	332	99
1260	1956.	0	0	1360.	0.	0	0	720.	2	56037.	696.	53988.	1532	150
1680	2604.	0	0	1360.	0.	0	0	720.	2	75487.	696.	73500.	1724	209
2100	3000.	0	0	1360.	0.	0	0	720.	2	95180.	696.	93264.	1724	275
2520	3348.	0	0	1360.	0.	0	0	720.	2	114940.	696.	113076.	1484	324
2940	732.	0	1	1372.	0.	1	0	708.	2	135032.	696.	133236.	1340	388
3360	0.	0	0	84.	0.	0	1	636.	2	153795.	696.	152056.	1628	437
3780	0.	0	0	0.	0.	0	0	720.	2	170094.	696.	168400.	1436	479
4200	0.	0	0	312.	0.	0	0	720.	2	188568.	696.	186928.	1676	527
4620	0.	0	0	0.	0.	0	0	720.	2	207640.	696.	206056.	1244	580
5040	0.	0	0	612.	0.	1	0	648.	2	225548.	696.	224020.	1460	629
5460	0.	0	0	0.	0.	0	0	720.	2	244777.	696.	243304.	1820	683
5880	0.	0	0	504.	0.	0	0	720.	2	262916.	864.	261328.	1676	733
6300	0.	0	0	444.	0.	0	0	720.	2	281759.	864.	280228.	1628	785

PRODUCTION DATA-
AWAITING X-RAY= 444.
AWAITING DECISION= 720.
ACCEPTED SHELLS= 281759.
TOTAL CLEARED= 282479. (18832.)
TOTAL PROCESSED= 286916.

MELTPOUR STOP TIME= 0 (0.0000)
LINATRON STOP TIME= 0 (0.0000)

NO. OF DEFECTIVES= 785
NO. OF X-RAYS TAKEN= 70453.
NO. OF SHELL X-RAYED= 864. WHILE SAMPLING
280948. WHILE SCREENING
281812. TOTAL (.9822)

MELTPOUR DOWN TIMES= 472 475 AVE. AVAIL.= .9248
LINATRON DOWN TIMES= 459 331 AVE. AVAIL.= .9353
USAGE TIMES= 5841 5574

HOLD CAPACITY EXCEEDED FOR 0 MINUTES (0.0000)

LENGTH OF TIME ON SCREENING= 6228 (.9886)

105MM LINATRON INSPECTION SIMULATION

NO. OF HOLD BUILDINGS= 2
NO. OF LINATRONS= 1
COOLING BUILDINGS SEEDED WITH 2048.
TOTAL HOLD SEEDED WITH 0.
TOTAL HOLD CAPACITY= 2816.
X-RAY HOLD CAPACITY= 1072.

MELT POUR FAILURE DATA- .001852 60.00 24.00 (NOMINAL AVAIL.= .9000)
LINATRON FAILURE DATA- .001754 30.00 36.00 (NOMINAL AVAIL.= .9500)

CRITICAL DEFECT RATES= .00300 WHILE SAMPLING .00300 WHILE SCREENING

I-NUMBER= 1820 WITH SAMPLING 1 OUT OF 4
LENGTH OF SIMULATION= 6300 MINUTES (15. SHIFTS)

MINUTE	COOL HOLD	MELTPOUR STATUS		HOLD	DUE	LINATRON STATUS		XRAY HOLD	MODE	FINAL OUTPUT	SHELLS SAMPLED	SHELLS SCREENED	KNUM	NDEF
420	4112.	0	0	2780.	0.	0	0	540.	2	13336.	516.	11880.	560	31
840	4112.	0	0	2780.	0.	0	0	540.	2	28823.	1500.	24048.	1820	69
1260	4112.	0	0	2780.	0.	0	0	540.	2	43900.	1500.	39168.	1748	109
1680	4112.	0	0	2780.	0.	0	0	540.	2	58975.	1500.	54288.	1244	150
2100	2480.	0	0	2780.	0.	0	0	540.	2	74045.	1500.	69408.	1820	197
2520	4124.	0	0	2780.	0.	0	0	540.	2	88150.	1500.	83556.	1640	237
2940	4124.	0	0	2780.	0.	0	0	540.	2	101422.	1500.	96876.	1568	282
3360	3764.	0	0	2780.	0.	0	0	540.	2	116499.	1500.	111996.	1820	322
3780	4124.	0	0	2780.	0.	0	0	540.	2	129854.	1500.	125388.	2676	359
4200	4124.	0	0	2780.	0.	0	0	540.	2	144931.	1500.	140508.	1712	400
4620	3908.	0	0	2780.	0.	0	0	540.	2	159992.	1500.	155628.	1820	454
5040	4124.	0	0	2780.	0.	0	0	540.	2	175002.	1536.	170640.	1424	492
5460	2324.	0	0	2780.	0.	0	0	540.	2	190078.	1536.	185760.	1532	532
5880	4112.	0	0	2780.	0.	0	0	540.	2	204037.	1536.	199764.	1352	576
6300	4112.	0	0	2780.	0.	0	0	540.	2	219110.	1536.	214884.	1820	621

PRODUCTION DATA-
AWAITING X-RAY= 2780.
AWAITING DECISION= 540.
ACCEPTED SHELLS= 219110.
TOTAL CLEARED= 219650. (14643.)
TOTAL PROCESSED= 221587.

MELTPOUR STOP TIME= 1989 (.3157)
LINATRON STOP TIME= 0 (0.0000)

NO. OF DEFECTIVES= 621
NO. OF X-RAYS TAKEN= 54240.
NO. OF SHELL X-RAYED= 1536. WHILE SAMPLING
215424. WHILE SCREENING
216960. TOTAL (.9791)

MELTPOUR DOWN TIMES= 723 467 AVE. AVAIL.= .9056
LINATRON DOWN TIMES= 188 0 AVE. AVAIL.= .9702
USAGE TIMES= 6112 0

HOLD CAPACITY EXCEEDED FOR 0 MINUTES (0.0000)

LENGTH OF TIME ON SCREENING= 6172 (.9797)

APPENDIX D

Fortran Program and Sub-Functions

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```
      PROGRAM LINATRN(INPUT,OUTPUT,TAPE5=INPUT)
      DIMENSION ISTLN(2),IDEC(2),LDOWN(2),PFAC(2),IFAC(2),LUP(2)
      DIMENSION SEXRAY(2),SVMIN(15),LUSED(2),RDEF(3,2),DEF(2),DEF1(2)
      DIMENSION ISTMP(2),         IUP(2),NDOWN(2),NSAMPD(5),KNUMD(5)
      DIMENSION SHELL(2),MODES(15)
      CALL DELAY
10    READ(5,500) NHOLD,NLIN,MINUTE,NPRINT,LSHIFT,IDEC
500   FORMAT(10I5)
      IF(EOF(5).NE.0.0) CALL EXIT
      IF(NLIN.LE.0) CALL EXIT
      IF(LSHIFT.LE.0) LSHIFT=420
      IF(MINUTE.LE.0) MINUTE=15*LSHIFT
      IF(NPRINT.LE.0) NPRINT=LSHIFT
      READ(5,500) (NSAMPD(I),KNUMD(I),I=1,5)
      SHIFT=MINUTE/FLOAT(LSHIFT)
  501 FORMAT(6F10.0)
      READ(5,501) FMP,RMP,PMP
      READ(5,501) FLN,RLN,PLN
      READ(5,501) HOLD,SEEDC,SEEDH
      READ(5,501) SAVEC,SEEDN
      READ(5,501) ((RDEF(I,J),J=1,2),I=1,3)
      AVM=FMP/(FMP+RMP)
      AVL=FLN/(FLN+RLN)
      FLN=1.0/FLN
      FMP=1.0/FMP
      DO 2000 IPLAN=1,5
      KNUM=KNUMD(IPLAN)
      IF(KNUM.LE.0) GO TO 2000
      NSAMP=NSAMPD(IPLAN)
      IFAC(1)=NSAMP
      IFAC(2)=1
      PFAC(1)=AMIN1(48.0,PLN*IFAC(1))
      PFAC(2)=AMIN1(48.0,PLN*IFAC(2))
      DO 1000 KDR=1,3
      DEF(1)=RDEF(KDR,1)
      IF(DEF(1).LE.0.0) GO TO 1000
      DEF(2)=RDEF(KDR,2)
      DEF1(1)=0.1*DEF(1)
      DEF1(2)=0.1*DEF(2)
      THOLD=SEEDH*NHOLD
      REXRAY=0.0
      TOUT=0.0
      INUM=KNUM
      QCOOL=2.0*SEEDC
      ISTOP=0
      LSTOP=0
      XRAY=0
      NDEF=0
      KTYPE=1
      MWHOLD=0
      MSCREEN=0
C     KTYPE=1=SAMPLE
C     KTYPE=2=SCREEN
      CHOLD=NHOLD*HOLD
      DO 14 I=1,15
      SVMIN(I)=0.0
      MODES(I)=0
```

```
14     CONTINUE
       DO 15 I=1,2
       ISTLN(I)=0
       SEXRAY(I)=0.0
       LDOWN(I)=0
       LUSED(I)=0
       ISTMP(I)=0
       NDOWN(I)=0
  15   CONTINUE
       PRINT 600,NHOLD,NLIN,SEEDC,THOLD,CHOLD,SAVEC
  600  FORMAT(1H1  /30X,36H105MM LINATRON INSPECTION SIMULATION/
      +30X,36(1H-)/1H0,20X,22HNO. OF HOLD BUILDINGS=,I2/
      +21X,17HNO. OF LINATRONS=,I7/
      +21X,29HCOOLING BUILDINGS SEEDED WITH,F6.0/
      +21X,22HTOTAL HOLD SEEDED WITH,F13.0/
      +21X,20HTOTAL HOLD CAPACITY=,F15.0/
      +21X,20HX-RAY HOLD CAPACITY=,F15.0)
       PRINT 604,FMP,RMP,PMP,AVM
604    FORMAT(1H0,20X,23HMELT POUR FAILURE DATA-,F10.6,2F7.2,
      +5X,16H(NOMINAL AVAIL.=,F6.4,1H))
       PRINT 601,FLN,RLN,PLN,AVL
601    FORMAT(21X,,22HLINATRON FAILURE DATA-,F11.6,2F7.2,
      +5X,16H(NOMINAL AVAIL.=,F6.4,1H))
       PRINT 602,DEF
602    FORMAT(1H0,20X,22HCRITICAL DEFECT RATES=,F8.5,
      +15H WHILE SAMPLING,10X,F8.5,16H WHILE SCREENING)
       PRINT 603,KNUM,NSAMP,MINUTE,SHIFT
603    FORMAT(1H0,20X,9HI-NUMBER=,I8,10X,22HWITH SAMPLING 1 OUT OF,I4/
      +21X,21HLENGTH OF SIMULATION=,I6,8H MINUTES,5X,1H(,F4.0,8H SHIFTS)
       PRINT 610
610    FORMAT(22H0MINUTE  COOL MELTPOUR,4X,4HHOLD,5X,13HDUE  LINATRON,
      +21H  XRAY  MODE      FINAL,         2(4X,6HSHELLS)/9X,
      +12HHOLD  STATUS,20X,13HSTATUS    HOLD,9X,6HOUTPUT,
      +         4X,7HSAMPLED,2X,19HSCREENED KNUM  NDEF)
       EXCESS=0.0
       DO 400 NMIN=1,MINUTE
       IF(MOD(NMIN,LSHIFT).EQ.0) CALL DELAY
       MSCREEN=MSCREEN+KTYPE-1
       DO 25 I=1,2
       IF(QCOOL.GT.4136.0) GO TO 26
       IF(ISTMP(I).NE.0) GO TO 20
18     XX=RUFF(DUM)
       IF(XX.GT.FMP) GO TO 21
       ISTMP(I)=1
       Z=DEVN(RUFF(DUM))
       REP=RMP+0.1*Z*RMP
       IUP(I)=NMIN+REP
       GO TO 24
20     IF(NMIN.LT.IUP(I)) GO TO 24
       ISTMP(I)=0
       GO TO 18
  21   QCOOL=QCOOL+PMP
       GO TO 25
24     NDOWN(I)=NDOWN(I)+1
25     CONTINUE
       GO TO 27
26     ISTOP=ISTOP+1
```

```
27    CONTINUE
      IF(THOLD.GT.CHOLD) GO TO 30
      TRANS=AMIN1(48.0,CHOLD-THOLD,QCOOL)
      QCOOL=QCOOL-TRANS
      THOLD=THOLD+TRANS
30    CONTINUE
      PLEFT=AMIN1(48.0,THOLD+REXRAY)
      IF(PLEFT.LE.0.0) GO TO 1351
      DO 135 I=1,NLIN
      SHELL(I)=0.0
      IF(ISTLN(I).NE.0) GO TO 119
117   IF(I.EQ.2.AND.(KTYPE+ISTLN(1)).EQ.1) GO TO 135
 118  SHELL(I)=AMIN1(PFAC(KTYPE),PLEFT)
      IF(SHELL(I).LE.0.0) GO TO 135
 1181 XX=RUFF(DUM)
      IF(XX.GT.FLN) GO TO 121
      ISTLN(I)=1
      SHELL(I)=0.0
      Z=DEVN(RUFF(DUM))
      REP=RLN+0.1*Z*RLN
      LUP(I)=NMIN+IFIX(REP)
      LDOWN(I)=LDOWN(I)+1
      GO TO 135
119   IF(NMIN.GE.LUP(I)) GO TO 120
      LDOWN(I)=LDOWN(I)+1
      GO TO 135
120   ISTLN(I)=0
      GO TO 117
 121  LUSED(I)=LUSED(I)+1
      PLEFT=PLEFT-SHELL(I)
      BMIN=AMIN1(REXRAY,SHELL(I))
      REXRAY=REXRAY-BMIN
      THOLD=THOLD-SHELL(I)+BMIN
135   CONTINUE
      GO TO 1352
1351  LSTOP=LSTOP+1
1352  CONTINUE
      MODESV=MODES(15)
      SHELLSV=SVMIN(15)
      SAVE=0.0
      DO 160 I=1,14
      SVMIN(16-I)=SVMIN(15-I)
      MODES(16-I)=MODES(15-I)
      SAVE=SAVE+SVMIN(16-I)
 160  CONTINUE
      MODES(1)=KTYPE
      SVMIN(1)=SHELL(1)+SHELL(2)
      SAVE=SAVE+SVMIN(1)
      IF(SHELLSV.LE.0.0) GO TO 180
      PIX=SHELLSV/IFAC(MODESV)
      DR=DEF(MODESV)+(RUFF(DUM)-0.50)*DEF1(MODESV)
      XRAY=XRAY+PIX/4.0
      NG=0
      PIX=PIX+EXCESS
      NSHELL=PIX
      EXCESS=PIX-NSHELL
      SEXRAY(MODESV)=SEXRAY(MODESV)+NSHELL
```

```
      DO 170 J=1,NSHELL
      IF(RANF(DUM).GT.DR) GO TO 170
      NG=NG+1
  170 CONTINUE
      TOUT=TOUT+NSHELL-NG
      RECALL=SHELLSV-NSHELL
      IF(NG.EQ.0) GO TO 175
      INUM=KNUM
      REXRAY=REXRAY+RECALL
      NDEF=NDEF+1
      KTYPE=2
      GO TO 180
  175 IF(KTYPE.EQ.1) TOUT=TOUT+RECALL
      IF(KTYPE.EQ.1) GO TO 180
      REXRAY=REXRAY+RECALL
      INUM=INUM-NSHELL
      IF(INUM.GT.0) GO TO 180
      INUM=0
      KTYPE=1
  180 CONTINUE
      IF(MOD(NMIN,NPRINT).EQ.0) PRINT 615,NMIN,QCOOL,ISTMP,
     +THOLD,REXRAY,ISTLN,SAVE,KTYPE,TOUT,      SEXRAY,INUM,NDEF
615   FORMAT(1X,I6,F7.0,2I3,F10.0,F8.0,I5,I3,F8.0,I5,3F10.0,2I6)
      IF(THOLD.GT.CHOLD) MWHOLD=MWHOLD+1
  400 CONTINUE
      TSHELL=TOUT+SAVE
      AVE=TSHELL/SHIFT
      AWAIT=THOLD+REXRAY
      PROC=TSHELL+2.0*SEEDC-COOL-AWAIT+NDEF
      PRINT 640,AWAIT,SAVE,TOUT,TSHELL,AVE,PROC
640   FORMAT(1H0,9X,16HPRODUCTION DATA-/15X,15HAWAITING X-RAY=,F13.0/
     +15X,18HAWAITING DECISION=,F10.0/15X,16HACCEPTED SHELLS=,
     +F12.0/15X,14HTOTAL CLEARED=,F14.0,4H   (,F7.0,1H)/
     +15X,16HTOTAL PROCESSED=,F12.0)
      AVE=FLOAT(ISTOP)/MINUTE
      PRINT 641,ISTOP,AVE
641   FORMAT(1H0,9X,19HMELTPOUR STOP TIME=,I7,3H  (,F6.4,1H))
      AVE=FLOAT(LSTOP)/MINUTE
      PRINT 646,LSTOP,AVE
646   FORMAT(10X,19HLINATRON STOP TIME=,I7,3H  (,F6.4,1H))
      DO 410 I=1,15
      PIX=SVMIN(I)/IFAC(MODES(I))
      XRAY=XRAY+PIX/4.0
      PIX=PIX+EXCESS
      NSHELL=PIX
      EXCESS=PIX-NSHELL
      SEXRAY(MODES(I))=SEXRAY(MODES(I))+NSHELL
  410 CONTINUE
      TSEX=SEXRAY(1)+SEXRAY(2)
      PCT=TSEX/PROC
      PRINT 642,NDEF,XRAY,SEXRAY,TSEX,PCT
642   FORMAT(1H0,9X,18HNO. OF DEFECTIVES=,I10/
     +10X,20HNO. OF X-RAYS TAKEN=,F9.0/10X,21HNO. OF SHELL X-RAYED=
     +F8.0,15H WHILE SAMPLING/31X,F8.0,16H WHILE SCREENING/
     +31X,F8.0,10H TOTAL    (,F6.4,1H))
      TDOWN=NDOWN(1)+NDOWN(2)
      AVAIL=1.0-TDOWN/(2.0*MINUTE)
```

```
      PRINT 643,NDOWN,AVAIL
643   FORMAT(1H0,9X,20HMELTPOUR DOWN TIMES=,2I5,5X,
     +12HAVE. AVAIL.=,F7.4)
      TDOWN=LDOWN(1)+LDOWN(2)
      AVAIL=1.0-TDOWN/(TDOWN+LUSED(1)+LUSED(2))
      PRINT 644,LDOWN,AVAIL
644   FORMAT(10X,20HLINATRON DOWN TIMES=,2I5,5X,12HAVE. AVAIL.=,
     +F7.4)
      PRINT 649,LUSED
649   FORMAT(18X,12HUSAGE TIMES=,3I5)
      PCT=FLOAT(MWHOLD)/MINUTE
      PRINT 645,MWHOLD,PCT
645   FORMAT(1H0,9X,26HHOLD CAPACITY EXCEEDED FOR,I5,8H MINUTES,
     +3X,1H(,F6.4,1H))
      PCT=FLOAT(MSCREEN)/MINUTE
      PRINT 647,MSCREEN,PCT
647   FORMAT(1H0,9X,28HLENGTH OF TIME ON SCREENING=,I6,3X,1H(,F6.4,1H))
      TPROD=TOUT+NDEF+SAVE
1000  CONTINUE
2000  CONTINUE
      GO TO 10
      END
```

```
      SUBROUTINE DELAY
      TSAVE=TIME(DUM)
      I1=SHIFT(TSAVE,-42).AND.7777B
      I2=SHIFT(TSAVE,-24).AND.7777B
      I3=SHIFT(TSAVE,-6).AND.7777B
      KK=I1+I2+I3
      DO 10 I=1,KK
      XX=RANF(DUM)
10    CONTINUE
      RETURN
      END
```

```
      FUNCTION DEVN(Z)
      DATA TOL/0.00005/
      DEVN=0.0
      IF(Z.LE.0.0) RETURN
      X=Z
      IF(X-0.50) 5,99,10
    5 X=1.0-X
   10 T=0.0
      PT=0.50
      DEL=1.00
   20 DIFF=X-PT
      IF(ABS(DIFF).LE.TOL) GO TO 98
      IF(DIFF) 30,98,40
   30 T=T-DEL
      DEL=DEL/5.0
   40 T=T+DEL
      PT=PERF(T)
      GO TO 20
   98 DEVN=T
      IF(Z.LE.0.50) DEVN=-DEVN
   99 RETURN
      END
```

```
      FUNCTION RUFF(Z)
      ICLTM=SECOND(A)*500.0
      K=(ICLTM-500*(ICLTM/500))/10+1
      DO 10 I=1,K
      TUFF=RANF(DUM)
   10 CONTINUE
      RUFF=TUFF
      RETURN
      END
```

```
      FUNCTION PERF(X)
      AX=ABS(X)
      T=1.0/(1.0+0.2316419*AX)
      D=0.3989422804*EXP(-X*X/2.0)
      PERF=D*T*((((1.330274*T-1.821256)*T+1.781478)*T
     +-0.3565638)*T+0.3193815)
      IF(X.GE.0.0) PERF=1.0-PERF
      RETURN
      END
```

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APPENDIX E

Critical Defect Definition and Inspection

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This appendix presents excerpts from two documents which specify the definition of a critical defect as applied to the 105 mm HE, M1 Cartridge and explain the procedure employed in the inspection for these critical defects.

Critical Defects

The definition of a critical defect for this product is set forth by MIL-C-45195D (PA), Military Specification, Cartridge, 105 mm, HE, M1, Loading, Assembling, and Packing. This document lists three categories of critical defects in Section 4.2.3.2 - Inspection for Cavitation:

1. Cavitation, cracks, or annular rings in Segment A, B, C, or D (see Fig E-1) in excess of that permitted in Table E-1.

2. Transverse cracks in excess of two for any charge or in excess of one in Segment A.

3. Separation of any kind between shell base and explosive charge.

Inspection

The procedure by which inspection for critical defects is conducted is contained in *MIL-STD-1235A, Single- and Multi-Level Continuous Sampling Procedures and Tables for Inspection by Attributes*. In particular, the plan called for by MIL-C-45195D (PA) is CSP-1, which is "a single-level continuous sampling procedure which provides for alternating between sequences of 100% inspection and sampling inspection with no limit as to the number of such sequences" and "requires a return to 100% inspection whenever a nonconforming unit is discovered during sampling inspection". The plan is governed by a choice of AOQL, or Average Outgoing Quality Limit. Once this value is selected, tables in the military standard provide pairs of the two key numbers for the plan, namely the F-number, or sampling frequency, and the I-number, or number of consecutive defect-free items that must be inspected 100% following detection of a critical defect before sampling can resume. Every time a critical defect is found, even while on 100% inspection, the I-number is reset. Table 3 provides the F- and I- numbers that were of interest in this study.

Table E-1

Critical defect specification

	(Segments see Figure E-1) A	B	C	D
Sum of projected areas of the cavities, excluding pipes, cracks and annular rings, square inch (sq. in.).	*1/64	1/4	1/2	1/2
Projected length of any cavity, excluding pipes, cracks, and annular rings (in.)	1/8	1/2	1/2	3/4
Piping cavities, maximum (max.) projected area (sq. in.).	0	1/4	1/2	-
Piping cavities, max. projected width (in.).	0	1/4	1/4	-
Cracks, max. projected width (in.).	1/32	1/32	1/32	-
Annular rings, max. projected width (in.).	0	0	1/4	-

*If the length of the largest cavity is 1/16 inch or less, the maximum total projected area may be 1/20 square inch. Piping cavitation is defined as cavitation located on or near the vertical center line of the projectile with the longitudinal axis (length) three times or greater than the width.

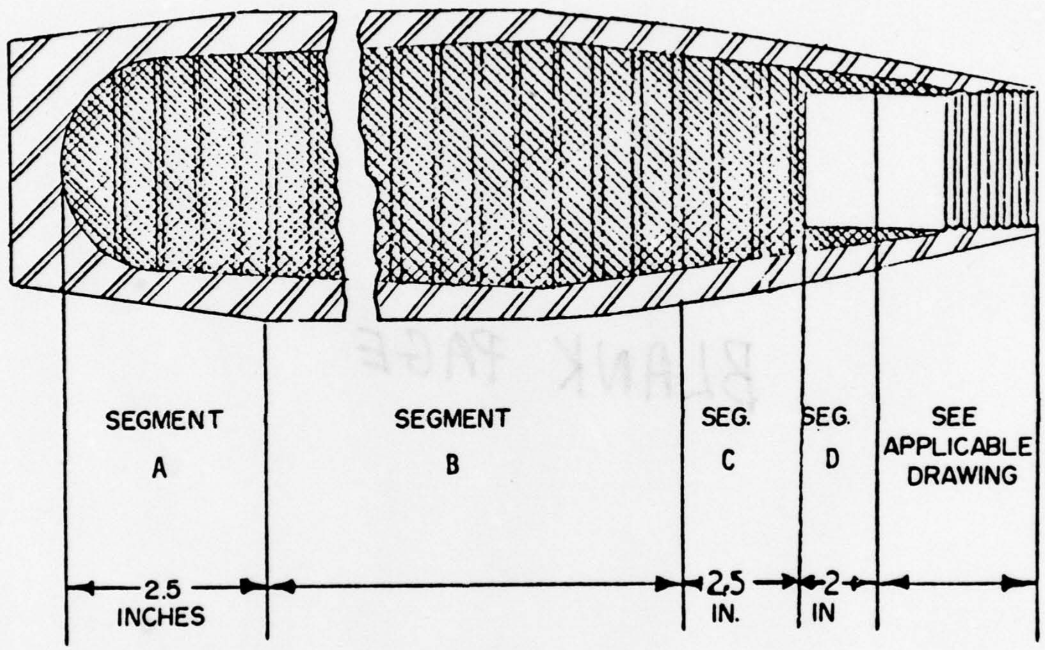

Figure E-1 Cross section of the 105 mm shell

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78